AN EVALUATION OF CONCEPTUAL THOUGHT UNDER CONDITIONS OF OXYGEN DEPRIVATION

By

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To

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and

M K M

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CHAPTER I

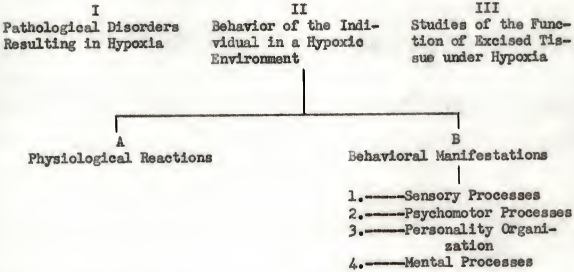
HISTORICAL BACKGROUND

Introduction

Lavoisier, in 1777, published a study entitled Experiments on the Respiration of Animals and on the Changes which the Air Undergoes in Passing through the Lungs. This is considered the first scientific treatise on the subject of oxygen utilization by the organism. Since this original work, the literature concerning oxygen deficiency has become voluminous. This broad field of research may be divided into three general categories:

1. Malfunctioning of various subsystems of the organism resulting in oxygen deficiency. For instance, heart, lung, blood, and circulatory disorders may alter the oxygen supply so as to be insufficient for tissue needs.
2. Externally imposed oxygen deficiency of excised tissue. The purpose of this research is to study the functioning of isolated organic tissue in the absence of oxygen. The investigation of neural conduction and synaptic transmission is perhaps the most noteworthy research in this area of investigation.
3. Oxygen deficiency brought about by subjecting the individual to an environment with reduced oxygen content, or an environment in which the partial pressure of oxygen is not sufficient

to maintain the normal absorption of oxygen by the blood stream. Figure 1 is a schematic diagram of research endeavor in the study of hypoxia.


I
Pathological Disorders Resulting in Hypoxia
II
Behavior of the Individual in a Hypoxic Environment
III
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A
Physiological Reactions
B
Behavioral Manifestations
1.------Sensory Processes
2.------Psychomotor Processes
3.------Personality Organization
4.------Mental Processes

Fig. 1. -- Areas of Research Concerning Hypoxia

Although the various categories listed are not mutually exclusive, they do offer a convenient means of organization of the factual information available. The present investigation is concerned with area II; the behavior of the individual in a hypoxic environment. More specifically, this study seeks to evaluate that aspect of behavior commonly referred to as the "higher mental processes."

Respiration and Hypoxia

To facilitate a better comprehension of the goal, method, and results of the present research, a general outline of the salient facts regarding the physiology of respiration will be reviewed. A detailed discussion of the very complex respiratory adaptation achieved by the human organism is not intended. A complete analysis of these processes would require a comprehensive study ranging from the physical properties of gases to the biochemical complexities of metabolism. For a more specialized treatment of this subject the works of Barcroft (3,4), Haldane (25,26), Henderson (30), and Peters and Van Slyke (51) are recommended.

The atmosphere is composed of approximately 21 per cent oxygen. The ratio of oxygen to other gases of the air does not change as altitude is increased; rather the density of the atmospheric components is decreased. The atmospheric pressure at sea level is 760 mm. Hg., of which oxygen contributes a partial pressure of 159 mm. Hg. It is important to recognize that it is the partial pressure of oxygen rather than the percentage which is decreased as one ascends to high altitude.

The smooth functioning of the respiratory system is dependent, in part, upon the partial pressure of oxygen which determines the rate of oxygen absorption by the hemoglobin. During inspiration, the air in the lungs is forced into the alveoli where oxygen is absorbed by the hemoglobin and transported by the arterial blood to the tissues of the body. The carbon dioxide resulting from cell metabolism is then absorbed by the venous blood and transported back to the lungs to be expelled. This entire system is dependent upon the partial pressures of oxygen and carbon dioxide. Diffusion between blood and cell takes place in the direction of least pressures; there is a pressure gradient between the inside and outside of the cell. Diffusion across the cell membrane is controlled by the range of this pressure gradient. As one ascends in altitude the partial pressure of oxygen is reduced, and the hemoglobin absorbs less oxygen to be carried to the tissues. Thus, with lessened oxygen tension, the rate of cell metabolism is reduced. The first physiological compensatory mechanism for lowered oxygen tension is an increase in respiratory volume. This is activated by stimulation of the chemeoreceptors of the cartoid sinus. However, this compensatory mechanism, which is quite adequate for the organism at sea level, is self-defeating in a situation of lowered oxygen pressure because the carbon dioxide tension of the arterial blood determines the dissociation of oxygen from hemoglobin. Thus, with the carbon dioxide being expelled as a result of increased respiration, the oxygen transported by the hemoglobin is not as readily available to the tissues. Hence the detrimental effect of this type of hypoxia takes place in three ways: (1) there is less oxygen in the blood; (2) the low carbon dioxide tension impedes the dissociation of hemoglobin; and (3) the rate of oxidation at the cell is diminished because of lowered oxygen tension (55).

The nature of the organism's adjustmental reactions to this stress is dependent upon the degree and the persistence of the hypoxia. If the stress is continued, in addition to the increased respiration, a rise in blood pressure will result. This permits more rapid transportation of the available oxygen to the tissues. Continued severe hypoxia will result in a lowering of body temperature, thus slowing down the metabolic reactions and creating a smaller demand for oxygen. Under conditions of prolonged exposure, the contraction of the spleen will furnish additional red blood cells for the transportation of oxygen to the tissues. The adjustmental reactions of the organism to hypoxia appear to be similar to the military concept of "defense in depth." A mild hypoxic stress is overcome by increased ventilation if the buffer system of the blood can maintain the proper pH value as a result of the decreased carbon dioxide. Additional stress requires compensatory reinforcements. The blood pressure is increased so as to hasten the transport of the available oxygen to the tissues. Continued stress requires the introduction of additional hemoglobin as a transportation vehicle. Finally, with continued severity and persistence of stress, the body temperature is lowered and less oxygen is required. Hypoxic stress continued beyond this point will be too great for the compensatory mechanisms to maintain organization, and unconsciousness and finally death will result if the condition is not relieved.

Peters and Van Slyke (51) suggest the following fourfold classification of anoxia:

1. Anoxic anoxia (anoxemia).--In this type there is a lack of oxygen in the arterial blood. The tension in the arterial blood is low; and the hemoglobin, therefore, is not saturated with oxygen to its normal extent.

2. Anemic anoxia.—The arterial blood contains oxygen, at a normal tension, but there is a shortage of functioning hemoglobin.

3. Stagnant anoxia.—Here, although the arterial blood has a normal amount of oxygen under normal tension, it is not given off to the tissues in sufficient quantities.

4. Histoxic anoxia.—As the term suggests, the tissue cells are poisoned and, therefore, unable to make proper use of the oxygen.

According to the above classification, anoxic anoxia is the type with which this investigation is concerned. However, since the term "anoxia" actually means "without oxygen" in a literal translation from the Greek, the term "hypoxia" meaning a subnormal supply is actually more descriptive of the situation. Recent investigators are looking with greater favor upon the term "hypoxia" as a replacement for "anoxia," except in those cases in which there is a complete lack of oxygen. For these reasons the term "hypoxia" will be used throughout this study.

Pre-Experimental Observations of Hypoxia

McFarland (43) offers an excellent summary of the literature prior to 1931 dealing with hypoxia under various conditions. A considerable portion of these references are from obscure government publications issued before and during the first World War and which are no longer available. For this reason, a major portion of the discussion which follows is abstracted from McFarland's very fine compilation of past observations and research in this area.

Many of the early reports of human behavior in a situation in which individuals were subjected to an environment which did not supply sufficient oxygen were largely of an accidental nature. The records of balloon ascensions, mountain climbing expeditions, and early fixed-wing aerial flights furnish a great many subjective observations dealing with human behavior under conditions of hypoxia.

Although balloon ascensions are noted as early as the flight made by the Montgolfier brothers in 1783, the first recorded observations of the effect of hypoxia at altitude were made by Robertson in 1804. The reports of his ascent indicate that he reached an altitude of 26,000 feet and did suffer some of the characteristic symptoms of hypoxia.

McFarland's vivid recounting of early subjective reports of hypoxia and its effects are of such interest that they warrant direct quotation. He describes the 1862 balloon ascension of Glaisher and Coxwell:

> In 48 minutes they reached an altitude of 28,000 feet and after that Glaisher found that he could no longer read his thermometer or watch. His last reading of the barometer was 248 mm. Hg., corresponding to about 29,000 feet. He found that his arms and legs were paralyzed and his neck so much so that he could no longer hold up his head. He could still vaguely see Coxwell who was trying to untangle a rope but when he tried to speak he could not, and then suddenly he became blind. He says, "I was still conscious and my brain as active as in writing these lines." Then suddenly he lost consciousness for about 7 minutes during which time Coxwell had succeeded in stopping the ascent of the balloon and even in bringing it down a considerable distance. During his return to consciousness he first heard words; then began to see his instruments vaguely, and finally was able to take up his pencil and make observations. This was at 26,000 feet. Coxwell had never lost consciousness, but noticing Glaisher's condition, tried to pull the valve rope.

> He found that his own arms were paralyzed, and then with great presence of mind got hold of the rope with his teeth. In this manner he opened the valve and caused the descent, thus saving Glaisher's life and his own (43, pp.18-19).

McFarland also cites Bert's tragic experiment which cost the lives of two of his friends and colleagues.

> Another very high ascent was made by three French scientists, Croce-Spinell, Sivel, and Tissandier in 1875. Bert reported the very graphic account of the symptoms they experienced as recorded by Tissardier, the sole survivor of this fatal balloon ascent.....In various ascents to about 25,000 feet and in Bert's steel chamber they had tested for the effects and had equipped themselves with bags of O_2. Unfortunately, the bags were small, so they decided not to use them until they felt really in need of oxygen. At 24,000 feet Sivel received the consent of his companions to cut loose the bags of sand serving as ballast in order that they might go higher. Tissandier, at 26,000 feet, reported that the condition of torpor which overcame him was extraordinary. "Body and mind became feebler, little by little, gradually and insensibly. There was no suffering. On the contrary one feels an inward joy.....I soon felt myself so weak that I could not turn my head to look at my companions. My mind was still clear, however, and I watched the aneroid with my eyes fixed on the needle which soon pointed to 280 mm. Hg., or 28,000 feet. I wished to call out that we were now at 8,000 meters but my tongue was paralyzed. All at once I shut my eyes and fell down powerless and lost all further memory." Tissandier's last records were scarcely legible and the repetition of words was very pronounced. In this ascent the balloon continued to rise until a pressure, recorded automatically, of 30,000 feet altitude was reached. When Tissandier recovered, one hour and a quarter later, the balloon was descending rapidly at 20,000 feet and both of his companions were dead. It was clear that they did not try to use the oxygen bags which they had prepared until it was too late—until they were so paralyzed they could not raise the tubes to their lips. Doubtless they were all convinced that they felt all right and in full possession of their faculties (43, pp.19-20).

Barcroft (3) makes the comparison of behavior observed during mountain-climbing expeditions and that experienced during intoxication. He cites depression, loss of emotional control, and drowsiness as characteristic symptoms. He also notes that memory is frequently impaired and that appreciation of time is altered. Barcroft is cited quite frequently for his analogies between chronic hypoxia and fatigue and between acute hypoxia and intoxication.

There have been a few experimental attempts to appraise the effect of hypoxia on mental ability during mountain climbing expeditions. However, the measures used were generally rather crude, testing conditions poor, and control of significant variables insufficient or absent. Barcroft (3,5), in an expedition to Cerro de Pasco (14,000 feet) in Peru, administered tests of memory for digits, multiplication, finding a duplicated letter in a series of letters, and telling the time by looking at the reflection of a clock in a mirror. On the whole there was no significant difference in the performance of the subjects at altitude. However, Barcroft notes that the tasks utilized may have been too simple and the subjects were probably able to compensate for the hypoxia by greater effort.

In evaluating the 1924 Mt. Everest expedition McFarland notes: "Hingston gave simple arithmetic tests to members of the party at 7, 14, 16, and 21 thousand feet. By increased effort of concentration they could be done quite easily, showing no loss of capacity. Also the tests were probably too simple to show up the subtle incapacities present (43, p.25)."

McFarland was the director of a comprehensive series of investigations of hypoxic effects at high altitudes in the Andes Mountains (44,45,46). In his evaluation of the complex mental processes in this situation he used numerous tests and measuring devices. Those of significance for this research are as follows:

1. Speed of apprehension. Tachistoscopically presented words at .35 of a second.
2. Transliteration of nonsense syllables from a code.
3. The rapidity of learning a code involving association of digits with symbols.
4. Memory for paired associates.
5. Color naming.
6. Perseveration tasks. These involved combinations of simple mathematical problems, writing letters of the alphabet, and drawing horizontal and vertical lines.
7. Judgment of temporal duration.
8. Thorndike CAVD Intelligence Test.

No attempt will be made to evaluate the results obtained from each of the above tests at the different altitudes. In brief, all measures showed a decrement in performance and an increase in variability at some point in the ascension to the maximum altitude of 17,500 feet. One exception to this generalization was the results of the CAVD test. Three subjects were tested with three different editions of the test at sea level, 9,200 feet, and 17,500 feet. There was a decrement in score of eight points at the highest altitude which was not a significant difference.

The author summarizes his results with the statement:

On the whole the mental tests involving complex reactions showed

> greatest relative loss in time and quality of response at the high altitudes, the motor tests second, and the sensory tests were least effected of all. The increased variability of response is attributed to alterations in the capacity for concentration associated with the more general physiological changes, as well as to those in the central nervous system alone (44, p.223).

In addition to the valuable observations of human behavior under hypoxic stress which we have gained from balloon ascensions and mountain climbing expeditions, the experiences of early aviators are also of interest. R. W. Schroeder reports his observations made during high altitude tests during the first World War. He notes feeling sleepy, tired, cross, and hungry. He reports:

> When I reached 25,000 feet I noticed the sun growing dim. I could hardly hear my motor run and got very hungry. The trend of my thought was that it must be getting late for the sun was so dim and I went on talking to myself. I then turned on the oxygen and the sun grew bright again, the motor became so loud that I thought something must be wrong with it. I was no longer hungry and I felt like singing from sheer joy (53, pp.906-907).

From his experience with the British Air Service during the first World War Birley (12,13) notes altered judgment, feeling of well-being, lassitude, general muscular fatigue, loss of sensory acuity, and muscular incoordination as symptoms of hypoxia.

Although much of the preceding is of an anecdotal nature and offers little in the way of quantitative evaluation, these experiences and observations furnished the stimulus for a more objective and controlled appraisal of hypoxic effects. In order to better understand the behavior and to devise precautionary measures for man's protection at high altitude the problems arising from these early experiences were taken into the laboratory.

Methods of Producing Hypoxia in the Laboratory

Numerous methods and devices have been used experimentally to bring about hypoxia in the individual. However, all are dependent upon one of three principles:

1. The pressure of the inspired air is reduced.
2. A limited amount of air is rebreathed so that the oxygen content is gradually diminished.
3. The oxygen content of the inspired air is diluted with nitrogen so as to provide arterial saturation equivalent to that found at specific altitudes.

The Dryer method (16) and the Douglas breathing bag method (15) of producing hypoxia utilize this latter principle. In both methods the oxygen concentration of the inspired air can be kept at any desired level. The Henderson-Pierce rebreather (31) and the Flack bag method (19) utilize the second principle in that body needs gradually reduce the amount of free oxygen available in a limited amount of air. The carbon dioxide is withdrawn from the system by a filter of caustic soda between the mouthpiece and the container. The low pressure chamber, as the name implies, is a method of reducing the pressure so that a smaller amount of oxygen is absorbed into the blood stream. Essentially, the low pressure chamber is a sealed container holding one or more individuals. It is so constructed that the air may be pumped out faster than it is admitted, thus lowering the internal pressure to some specified degree. The larger, more elaborate chambers, such as was used in this experiment (Fig.15, Appendix), will accommodate 10 to 12 individuals. Observation windows are constructed in the side of the chamber so that outside observers may keep a close check on the subjects of the experiment. Radio communication between the subjects and outside observers is available. Bottled oxygen with appropriate masks are placed at intervals throughout the chamber for use in emergency or by inside observers during an experiment.

These various methods of producing hypoxia may not be directly comparable in terms of the physiological and psychological effects produced. For instance, with the Douglas rebreather apparatus the oxygen content of inspired air is gradually lowered as it is absorbed by the organism. However, in the chamber and the oxygen dilution methods the oxygen content of inspired air can be maintained at any constant value. In addition, the hypoxic effects produced by the chamber and dilution methods may also follow a different pattern because in the latter method sea level atmospheric pressure is maintained while in the former method the oxygen percentage of inspired air is the same as at sea level but the total pressure is reduced. For these reasons, it is important to note by which method hypoxia was produced in evaluating the results of research in this area. It is generally conceded that the low pressure chamber most closely approximates the conditions found at high altitude and is the preferred means of experimental investigation of hypoxic effects.

Gross Manifestations of Hypoxia

Haldane described behavior observed in the decompression chamber which is quite similar to the reports made of balloon ascensions and mountain climbing expeditions.

> There is loss of awareness of incapacitation, the intellect becomes dulled, memory is affected early and is finally almost annulled so that persons who have apparently never lost consciousness can nevertheless remember nothing that has just occurred. Often a more serious danger arises from the gradual and insensible failure of sane judgment. A person may become subject to irrational fixed ideas and to uncontrolled emotional outbursts. Without reason he may begin to shout, sing, burst into tears, or become dangerously violent (25, pp.125f).

Barcroft (3) spent six days in a glass chamber at Cambridge where the partial pressure of oxygen was varied, corresponding to altitudes from 10,000 to 18,000 feet. There were minor changes in simple mental tests of memory, multiplication and discrimination. He observed that the highest faculties were the first to be affected, for in working the Haldane Gas Analysis apparatus he could not make the necessary discriminations, yet he could carry out the correct responses if clear commands were given for each movement.

In 1923 Lowson (40) made a psychological study of the effects of low oxygen tension in the chamber at Cambridge. Five subjects were given tests of speed of tapping, accuracy of aiming, speed of card sorting, substitutions, analogies, distorted sentences, and a same-opposite test. After six daily practice periods the subjects were required to perform the tests inside the chamber. Lowson found that on the average the alterations in behavior were not significant until the diminution of oxygen reached 50 per cent of the normal, or approximately 20,000 feet, but at that point changes were frequently quite rapid and great.

Another study of the psychological effects of hypoxia was undertaken by Tanaka (54). This experiment consisted of giving six subjects the following tests: speed in simple and complex card sorting, addition, memory, strength of grip, quality of hand writing, and auditory, tactual, and visual choice reaction time. Tanaka's results show that the performance curves in all of the tests decrease gradually until they reach 15,000 feet where they descend suddenly. Tanaka concludes: (1) there are great individual differences as to the altitude at which changes occur; (2) the effect is more marked in mental than physical work, and the more habitual the task, the less the effect; and (3) in many kinds of work there is a critical point where a sudden change occurs, usually at about 428 mm. Hg. of pressure, or at 15,000 feet above sea level.

Sensory Functions

A number of the early studies were made to determine the effect of oxygen want on simple sensory mechanisms. Wilmer and Berens (57), utilizing both the chamber and the rebreather apparatus, found no very marked visual effects at altitudes below 10,000 feet. At 15,000 feet slight deficiencies were noted, and at 20,000 feet, or over, definite impairment of visual functions appeared.

McComas (41) reports that studies made of convergence and accommodation revealed considerable loss of strength of the muscles of the eye. It was noted that at heights between 10,000 and 15,000 feet the subjects with slight convergence would experience double vision.

Experiments on aviators in the United States Air Force showed that a diminished oxygen supply exaggerated to a marked degree any existing eye defects and unmasked pre-existing conditions which otherwise would have eluded detection. Crash reports of aviators demonstrate that a large proportion are due to such eye defects (58).

Johnson and Paschal (35) indicate that many of the disturbances attributed to vision are more probably attentional than sensory. They have noted that as collapse approaches there is a great depression of vision manifested, not in the blurring of outlines but in a general darkening of the visual field and an intermittent cessation of all visual experiences.

Lewis, summarizing the effect of hypoxia upon auditory sensitivity, states: "The hearing function shows no deterioration prior to the degree of oxygen deprivation that causes acute functional impairment of all of the higher cerebral, sensory and psychic centers. The condition is signalized by the onset of semi- or un-consciousness (38, p.1399)."

The experiments of Lewis (38,39) and Head (28) furnish evidence that hearing is retained longer than any other sensory function and returns first upon administration of oxygen.

Aviation Selection Research

Dunlap (17, 18), in an effort to develop hypoxia tolerance measures for aviators during the first World War constructed several measures of performance under hypoxia. The tasks he used were (1) a discrimination reaction time apparatus, (2) a rotary pursuit instrument, and (3) a combination pitch discrimination and motor coordination apparatus. In brief, the results showed:

> ...a restriction in the field of attention and loss of control over finer movements. The first symptoms were usually noted after 15 minutes at approximately 14,000 feet. The subjects then frequently improved, due to the extra effort exerted, and apparently succeeded in "pulling themselves together" for a short time. Soon, however, they began to deteriorate and at 25 minutes failed very badly. Eventually they became wholly inefficient or unconscious and were removed from the machine, being unaware of the extent of the alteration of behavior. Occasionally other reactions appeared, such as silly laughter, anger and even destructiveness (13, p.95).

Dockeray, Dunlap, and Johnson (14) directed a series of investigations for the United States Air Service. The rebreather apparatus was used to reduce the oxygen percentages. From 10 to 12 pilots served as subjects in each experiment. The tests included card sorting—based upon visual and tactual discrimination, a code test involving transliteration of letters, simple tests for memory and mathematics, continuous reaction to 24 automatic lights, and a dynamometer. In the code test, deterioration of convergence and accommodation in reading were first noted, and motor control was affected early. The neuro-muscular efficiency as shown in the dynamometer test, however, was not impaired until the final stages of hypoxia. The experimenters state:

> In all of the tests there was no very noticeable difference between the control and the rebreather series until the time of general psycho-motor decline. This was due to the strong tendency of the subjects to compensate for the effects of oxygen want until the deprivation became too great. This tendency was manifested in "attention peaks" even in relatively late stages of asphyxiation. Practice in enduring asphyxiation seemed to have an effect in increasing efficiency, for an individual learned to husband his resources. Tenacity or "grit" counted a great deal. The detection of this trait in itself was of great value (14, p.304).

By way of summary of the extensive work on pilots during the first World War, Dunlap and his associates conclude that:

> The primary and important psychological effects of oxygen want are on voluntary coordination and attention, for, until the final stages of asphyxiation, no effects are demonstrable which are not clearly a failure of one or both of these factors. Sensitivity and perception remain as efficient as muscular control of the sense organs and power to attend to stimuli permit. Speed of simple reactions is apparently not reduced, and discrimination shows no falling off in rapidity or accuracy, except as produced by impaired motor control. Likewise, memory and other higher mental processes are not affected, except as decrease in ability to attend to details in learning appears, or increased distractibility or muscular incoordination (18, p.95).

Complex Mental Processes

McComas (41, 42) tested simple and choice reaction time at altitudes of 6,000, 14,000 and 20,000 feet. He reports that at an altitude of 14,000 feet speed was sacrificed for accuracy and that there was a narrowing of the field of attention to the task at hand. At 20,000 feet deterioration was marked with symptoms of drowsiness and the higher functions of the subjects were markedly effected.

In 1920, Johnson and Paschal (35) reported a study of the deterioration of the mental functions involved in the speed and accuracy of transliterating sets of nonsense syllables into corresponding codes. The essential feature of the study was to determine whether the more complex processes of behavior tend to deteriorate before, after, or simultaneously with the simpler processes. The substitution test was used, "since the task involved sustentation of vision, attention, memory, and neuromuscular coordination during a longer period of time than could be included in a voluntary spurt or by simply exciting greater energy (35, p.205)." It was assumed therefore that this test might reveal the subtler effects of oxygen want considerably before collapse approached. Thirty-one subjects were tested with a Henderson-Pierce rebreather for approximately a half-hour period, during which time the oxygen percentage was depleted from normal down to 7 per cent (31,000 feet).

McFarland (43), in summarizing this experiment, states:

> The results revealed that no general laws or standardized performances could be made because of great individual differences. In some cases performance steadily improved until collapse approached. The results in general indicate that simpler sensory-motor reflexes, as a rule, do not exhibit noticeable impairment until deterioration of the more highly organized responses has reached an advanced stage. They suggest that the deleterious effect of low oxygen causes interference at the synapses and that, therefore, the processes which show impairment first would involve those of the highest degree or organization of neuro-muscular arcs (43, p.37-38).

In 1921, Bagby (2), using rebreathing apparatus, evaluted sensory-motor performance using tests of aiming, tapping, knee jerk, simple reaction time, and visual, auditory and tactual sensitivity. He also included several tests of immediate and delayed recall of verbal material. Bagby concludes that the most obvious effects of oxygen want are the production of tremor, muscular incoordination and motor discharge.

> The central nervous system becomes less and less integrated with increasing oxygen deprivation. Higher mental functions are apparently not effected until there is a loss of motor control and attention associated with the symptoms of impending collapse. Many subjects reported difficulty in "pulling themselves together" and they constantly wanted to rest. The customary "spurt phenomena" or temporary improvement in performance was present, due to the periodic application of greater effort (2, p.108).

Ross McFarland is perhaps the most frequently cited research scientist in the area of the behavioral effects of oxygen deprivation. His extensive research at Cambridge (43) included an appraisal of the results of hypoxia upon sensory, psychomotor, and the more complex mental processes. For the purposes of this paper we are interested primarily in his conclusions regarding the hypoxic effects on the higher thought processes. Using the oxygen dilution method, McFarland evaluated susceptibility to hypoxia by means of performance measures of simple and multiple choice reactions. The general conclusions from this research were: (1) simple reaction time and sensory-motor responses are not seriously impaired until the subject approaches collapse and then the loss appears fairly sudden; and (2) in the case of choice reactions the detrimental effects are greater, come earlier, and the deterioration appears to be gradual and in proportion to the amount of oxygen deprivation. McFarland analyzed his data in terms of mean decrement of performance as a function of increasing altitude. Although he noted considerable variability in the behavior measured and occasional efficient performance during periods just prior to collapse, the author accounted for this phenomenon with the concepts of attention, motivation, and effort. He seemed to conceive this behavior as a variable which contaminated the data so as to conceal the effects of hypoxia. In discussing this situation McFarland states, "The subject, as the effects of oxygen want become more marked, has temporary lapses, and then he pulls himself together again. This greater effort put forth tends to conceal the real effect of oxygen want (43, p.109)."

In a more recent publication McFarland and Barach (48) sought to evaluate differences in performances of psychoneurotics and normal controls at simulated altitudes of 12,000 and 20,000 feet. The tasks utilized in this investigation included form boards, code test, and parts three to seven, inclusive, of the Army Alpha test. The results indicated a significant decrement in performance for both groups in the form board tests at both altitudes tested. A significant decrement was noted for the patients in their performance in the code and the Army Alpha test at 12,000 feet. There was no significant difference in the performance of the normal controls on the Army Alpha test. An increase in variability was noted in all measures. McFarland indicates that the large standard deviation frequently found in measurements obtained from experiments of this nature often prevents a significant difference from appearing in the means and hence makes difficult a conclusive statement regarding the point at which decrement occurs. He also cites the wide inter- and intra-individual differences that are frequently present as another factor which act to obscure definite results.

Gellhorn (20), utilizing the oxygen dilution method, measured performance on a cancellation test, arithmetic, and a paired associates memory test. The results of this research showed a significant decrement in all tests utilized. He also demonstrated that impairment of performance could be eliminated by the introduction of 3 per cent carbon dioxide which acted to stimulate respiration.

Kraines (37) sought to evalute the performance of 30 subjects at a simulated altitude of 20,000 feet for a period of 16 minutes, using the Army Alpha Intelligence Test. The various subtests were given in sequence throughout the 16-minute period. The author found a slight increase in proficiency during the first five minutes of hypoxia. After this point, however, a decrement appeared which increased through the last test given during the final three minutes of the testing period. The author concludes: "Thus it would seem that the condition of anoxemia present in the beginning has been compensated for, but that the compensation tended to fail later owing to a decrease in carbon dioxide in the blood (37, p.1444)."

Russell (52), in a well controlled experiment, attempted to determine the effects of hypoxia on human behavior. He simulated an altitude of 18,000 feet in a decompression chamber. The tests used to measure decrement of performance were finger dexterity, arm-hand coordination, and simple addition. The subjects were maintained at altitude for a period of 35 minutes. The trends for all three tasks were the same and the results may be summarized together. Russell found, in contradiction to some of the earlier research, that there was an immediate decrement in performance after exposure to mild anoxia. In addition, a rapid adjustment to the hypoxia occurred so that the experimental subjects continued to improve in performance to a degree approaching their proficiency under sea level conditions.

The Blocking Effect

In 1931, A. G. Bills (8) announced the discovery of a new principle of what he called "mental fatigue." He called the principle the "blocking phenomena." A "block" was tentatively defined as referring "to those periods, experienced by mental workers, when they seem unable to respond, and cannot, even by effort, continue until a short time has elapsed (8, p.230)." Bills found that the blocking phenomena were most prevalent in those tasks which were homogeneous and in which the subject's responses were required to be repetitive and continuous. Bills tested this hypothesis by means of such tasks as color naming, alternate addition and subtraction, naming opposites, and code tests. As a result of this experimentation, he defined a block as "a pause in the response equivalent to the time of two or more average responses (8, p.231)." This concept was quite significant to a large body of research dealing with fatigue. The common finding in this field was that the general efficiency of performance in many tasks was maintained in spite of long periods of prolonged work. Bills postulated that the increase in frequency and length of blocks in continuous work compensated for the increasing fatigue. The author attempted to account for the blocking phenomena by means of the concept of a "cumulative refractory phase," which in essence was merely an extension of the refractory phases noted in a single nerve fiber.

In later studies (9, 10), Bills sought to determine the influences of homogeneity and number of conflicting elements in the task as determiners of the frequency and amplitude of blocks. Again he used modifications of a color naming test. On the basis of this research he concluded: (1) in the case of material containing elements, the frequency and length of the blocks are proportional to the number of such elements; and (2) the frequency and length of the blocks are directly proportional to the number of conflicting elements involved. Bills suggested a third hypothesis to the effect that if it were not for the appearance of the blocks the decrement in performance would be greater.

Bills seemed to recognize in this paper that his explanation of blocking as a function of the cumulative refractory phase was not quite adequate. The principle might apply in a simple repetitive task such as naming three colors. However, in a task involving a large number of colors in random order so that the subject could not anticipate the appearance of the succeeding stimulus, the refractory principle would not suffice since it could not possibly be maintained that any isolated area of the nervous system was being repeatedly excited in such a situation. This latter task Bills considered as one that involved conflicting elements.

Bills (11) also attempted to determine whether the appearance of blocks was a function of the amount of time elapsing or a function of the amount of work accomplished in a specified time interval. He concluded that the number and size of blocks, as measured in a color naming experiment, is a result of the amount of work done rather than a function of a rhythmical neural sensitivity fluctuation throughout a temporal interval. In addition, he found that he could not explain the behavior on the basis of oscillation of a single energy system; i.e., being depleted by work, restoring efficiency during the block periods, and again being depleted by further work. Bills summarizes:

> The data seems to require interpretation in terms of more than one simultaneous rate of oscillation in neural energy, so that the resulting time curve can be accounted for only as a composite effect of the component frequencies, in the sense that a complex sound wave can be analyzed into its harmonic components. The necessity of such an interpretation proves that the traditional concept of a single energy component, call it attention, or what you will, was entirely inadequate to explain the facts. The organism in performing mental work is not utilizing a single unitary energy, but is drawing upon a number of relatively independent energy components, each of which can be expected to have its own peculiar oscillation rate. Output is the resultant of the interaction of all of them. There is the refractory period of the sensory component, the peripheral neural and central neural components, etc., (11, p.571).

This explanation of the blocking phenomena appears to be a refinement of the earlier simple refractory phase interpretation. According to the above principle, the characteristics of the work curve are determined by the contributions of separate energy components and are not a function of the total neural organization at any given moment.

Bills also sought to answer the question as to whether or not the blocks served as automatic rest periods operating in such a way as to maintain constant performance. He interspersed forced rest periods in a color naming test at those points which had been predetermined as likely to include a block. He answered the question in the affirmative as he succeeded in eliminating many of the blocks through this introduction of rest periods.

A comparison of the data obtained from experiments in fatigue and those obtained under hypoxia was undertaken by Bills (11). In a color naming experiment at a simulated altitude of 12,000 feet, he found that the frequency and amplitude of blocks were comparable to those obtained after an hour's continuous work at sea level. The blocks made their appearance much sooner under the hypoxic conditions than at sea level but there was no change in the modal response in either condition. The author concludes from this work that the gradual depletion of neural energy necessitated frequent forced pauses.

Aside from the validity of Bills' explanation of the blocking phenomana, he was the first to recognize this variability as a significant aspect of behavior and not merely as a fluctuation in attention and effort which acts to conceal the "real" hypoxic effect.

Current Status of Research

We have considered briefly the physiological reactions to hypoxia and in some detail have evaluated the experiments dealing with the behavioral manifestations.

In our review of the literature we have considered numerous specific experiments dealing with the decrement of various aspects of human behavior under conditions of hypoxia. In conclusion, we will indicate briefly the current status of scientific knowledge in this area.

In a recent symposium, McFarland, summarizing the effect of hypoxia on psychological phenomena, states: "The psychological deterioration at altitude is characterized not merely as a general slowing up of mental functions and a greater amount of effort needed to carry out the task but also with qualitative changes (47, p.343)."

Armstrong, in a survey of the literature dealing with mental functioning under hypoxia, writes:

> Most recent writers agree that there are no psychologic changes from hypoxia even during prolonged flights at altitudes below 9,000 feet. Above this altitude, however, psychologic changes begin to appear and the degree of change, as is the case with physiologic processes, is in proportion to both the altitude and to the duration of exposure (1, p.210).

Thus the present state of our knowledge in this area portrays a decrement of efficiency continuous with the degree and duration of hypoxic stress.

On the other hand, our knowledge of the adjustmental reactions to hypoxic stress indicates that the organism reaches a "steady state" brought about by the body's compensatory mechanisms. Apparently, then, we have a discrepancy between the behavior of the organism under hypoxic stress and that which we would expect from our knowledge of the physiological adjustment mechanisms.

Although not specified as such, many descriptions of human behavior in a hypoxic environment infer the existence of the blocking effect. For instance, Dunlap (13) attributes the great variability of performance to the extra effort exerted by the subjects. He observes that they periodically succeeded in "pulling themselves together." Dockeray, Dunlap, and Johnson (14) note "attention peaks" and tenacity or "grit" which account for the interspersed periods of stable and impaired performance. Bagby (2) attributed the periods of efficient performance to the "spurt phenomena...due to the periodic application of greater effort." In summarizing his work, McFarland (43) states, "The subject, as the effects of oxygen want becomes more marked, has temporary lapses, and then he pulls himself together again. This greater effort put forth tends to conceal the real effects of oxygen want."

The results of these studies were based upon an evaluation of the mean decrement of performance, which was considered the true index of the effect of hypoxic stress. The periods of efficient performance were viewed as the result of variables which contaminated the data so as to conceal the real effects of hypoxia. Although these investigators observed what might be termed the blocking effect, the variability of performance was accounted for through flucuations of attention, motivation, and effort. As a consequence of his fatigue studies Bills (8, 9, 10, 11) demonstrated that the behavior deviations in his experiments were systematic variations.

It is quite conceivable that the discrepancy between physiological homeostasis and continuous behavioral decrement may be resolved through a consideration of the blocking effect.

The present study is an attempt to evaluate the nature and characteristics of performance impairment as a function of hypoxic stress. In the following chapter we will consider specifically the problems to be investigated in this research effort.

CHAPTER II

STATEMENT OF THE PROBLEM

Introduction

Essentially the goal of this research is to test certain hypotheses regarding the impairment of behavior under conditions of hypoxic stress. The first task will be to demonstrate that there is a decrement in the efficiency of performance being evaluated. We will then attempt to determine if, and to what extent, the blocking effect is present in the execution of the task utilized in this investigation. Finally, we will investigate the relationship between continuous hypoxic stress and efficiency of performance.

Hypotheses

Hypothesis I. It is apparent from a review of the literature that there has been little if any actual evaluation of the more complex thought processes in a hypoxic environment. We have noted isolated tests of memory, simple arithmetic operations, choice reaction time, code substitution, and other relatively simple tasks. However, in none of these investigations do we note what might be considered a complex mental task or one requiring reasoning and judgment. That is, most of the tasks utilized in previous studies were such that the component elements, if not the tasks themselves, could easily become habitual and automatic. McFarland recognized this situation, for, as he reports, "precise experiments in regard to such mental functions as judgment and insight are difficult to carry out because of the lack of objective tasks (47, p.344). In an effort to meet this need, an instrument was developed for use in this investigation which will be referred to as the Conceptual Reasoning Test.

Obviously, if we are to analyze the relationship between hypoxic stress and decrement of performance we must first show that there is actually a loss of efficiency in the performance which we are evaluating.

We have noted in our review of the literature that the more complex the task, the earlier a decrement in performance is likely to appear. In addition, the results of research concerning performance under hypoxia indicate that for many tasks there is no measurable decrement in performance at the lower degrees of stress. Thus, the achievement of the goal of this research apparently is dependent upon the complexity of the task which the subjects are required to perform and the degree of hypoxic stress under which the measurements are obtained. To determine if we have constructed a task which is sufficiently sensitive to register a loss of efficiency under the hypoxic stress specified we will test the following hypothesis:

> Hypothesis I. For the task utilized in this investigation, there is a significant difference between the efficiency of performance at sea level and all other simulated altitudes in which measurements were obtained.

Hypotheses II and III. Assuming that the above hypothesis is accepted, our major goal is to evaluate the nature or characteristic of this decrement. To achieve this end we will utilize Bills' concept of the "blocking effect;" i.e., "those periods, experienced by mental workers, when they seem unable to respond, and cannot, even by effort, continue until a short time has elapsed (8, p.230)."

From a strictly behavioral point of view, a block is a temporary failure to respond in some specified manner. We assume that this block, or failure to respond, is a symptom or sign of the condition of the organism. In other words, we imply some physiological change of functioning from the behavior we observe. It is not the purpose of this paper to determine the physiological background responsible for the occurrence of behavioral blocks. However, it is the author's intention to determine if such blocks do appear in the performance being evaluated and, if so, to determine their relationship to degree and duration of stress.

Using a color naming task, Bills (8, 11) found the block effect present under conditions of fatigue and mild hypoxia. It is proposed that response blocks will appear in the task utilized in this investigation and at the simulated altitudes under which the measurements are obtained. We will evaluate this proposal by testing the following hypotheses:

Hypothesis II. There is a significant increase in the frequency of blocks with degree of stress.

Hypothesis III. There is a significant increase in the frequency of blocks with duration of stress.

Hypothesis IV. It is the thesis of this paper that the relationship between decrement of performance and duration of hypoxic stress is saltatory, or stepwise, rather than continuous. By the latter relationship is meant a situation in which efficiency decreases continuously as duration under stress increases. Or, stated differently, the longer the person remains in a hypoxic environment the less efficient becomes his performance. A saltatory relationship is one in which the decrement in performance occurs in steps rather than as a continuous function of the duration under stress. That is, the individual maintains uniform performance for a period of time in the face of increasing duration of hypoxic stress. By analogy, the difference between the continuous and saltatory relationship is similar to descending from a height by means of a ramp or by means of a staircase. In the former situation we have a continuous relationship between height and rate of descent; in the latter we have a saltatory relationship.

In accepting the saltatory relationship, it is assumed that as the organism is subjected to hypoxic stress certain physiological compensatory mechanisms are brought into operation which maintain a constant arterial oxygen supply as the stress is continued. This "steady state" is preserved until just prior to unconsciousness at which time the compensatory mechanisms fail to maintain stability and there is a sudden drop in the arterial oxygen concentration. It is believed that this physiological adjustment to a stress situation is reflected in a corresponding manner in the subject's performance. We should expect an early drop in proficiency followed by a period of constant performance which is continued until the period of collapse.

The rationale for the thesis that this relationship is saltatory is based upon the phenomenon of the block effect. We will assume with Bills that there are periods of time under stress during which the subject is unable to respond. That these periods increase in frequency with duration and degree of hypoxic stress will be tested by Hypotheses II and III. The saltatory relationship is evidenced by performance between or excluding these block periods. In other words, our conception of the deterioration of performance is that after an initial decline the subject maintains a constant and uniform level of efficiency, and that throughout this period there are intervals during which the subject experiences blocks and seems unable to respond. As duration of stress is increased, the frequency of blocks increase, so that lucid intervals and uniform performance become less frequent and the periods of response blocks become more frequent. However, even during the final moments prior to collapse there are times during which the individual performs at a level comparable to his efficiency in a nonstress situation. This proposal is suggested as an alternative for the current conception that efficiency declines continuously with stress; i.e., performance gradually slows down and finally ceases at the time of unconsciousness.

If in our analysis we consider those responses which include blocks, the relationship will necessarily be continuous because with such a procedure we are measuring periods of time during which the subject apparently is not responding. If these periods increase in a continuous manner with duration of stress, the measures of performance decrement must also portray a continuous decrement. This situation would also be true if the measures were other than in terms of time to complete a task. For instance, if frequency of error, total score, or variability were used to measure the impairment, we would obtain a continuous decrement if the block effect were not taken into consideration in the analysis of the data. If, as Bills maintains, blocks are automatic rest periods taken by the organism, the inclusion of these rest periods in the analysis of the data does not provide an accurate portrayal of the subject's behavior while actually performing under stress. By inclusion of the block responses, information is obtained regarding the subject's total production. Such a procedure does not inform us regarding the actual behavior of the subject during the period under stress.

It is the goal of the present investigation to evaluate the nature or characteristics of performance rather than merely to determine work production curves under various degrees and durations of hypoxic stress. If in our analysis we omit those responses in which blocks occur, the nature of the decrement will be saltatory rather than continuous. We will evaluate this proposal by testing the following hypothesis:

Hypothesis IV. The relationship between the decrement of performance and continuous hypoxic stress is saltatory.

Summary

The essential problem of this research is to demonstrate that there is a measurable decrement in conceptual reasoning ability as a function of degree and duration of hypoxic stress. Further, it is hypothesized that the decrement in performance exhibits a saltatory, rather than a continuous, relationship with duration under stress, that the saltatory decline is dependent upon the appearance of response blocks, and that these increase in frequency with degree and duration of stress.

CHAPTER III

METHODOLOGY

Subjects

Volunteers for this research were requested from the enlisted men of the Naval Air Basic Training Command. Ten men were selected from this group to participate in the experiment. They were given complete physical examinations comparable to that required of Naval aviators. All were within the age range of 18-20 years, in good physical health, of average intelligence, and without apparent personality disturbances.

The subjects were given indoctrination lectures concerning the symptoms that might be experienced at high altitude. They were also given a demonstration in the use of oxygen equipment and general instructions concerning safety in the decompression chamber. Trial runs were made prior to the experiment to acquaint them with the general nature of hypoxia and to relieve any anxiety in connection with the experiment.

Inasmuch as these men were to serve as subjects in additional research, the present experiment was explained to them as one phase of a larger project in the general area of high altitude flight. The purpose of the present investigation was stated as being a study of "thinking ability" at high altitude. This explanation and the general value of the project seemed to have face validity for Naval Aviation and were accepted by the group. The genuine acceptance and cooperation of the subjects were demonstrated continuously during the entire experiment.

In spite of headaches, nausea, "bends," and general discomfort, none of the subjects withdrew from the experiment, and all demonstrated a consistently high level of motivation and interest throughout the investigation.

Performance Task

There are few tests applicable to research in this area. This situation is quite easily explained. In order to evaluate the decrement in complex mental processes resulting from hypoxia, the tests utilized must meet the following prerequisites:

1. The task has to be such that it actually involves the complex thought processes and is not one that may become habitual or automatic.
2. The task has to be sufficiently sensitive to permit the measurement of slight variations in performance.
3. The elements of the task, or individual problems, have to be homogeneous in nature and of equal or known difficulty.
4. Although requiring concentration, reasoning, and judgment, the problems have to be such that they may be solved in a relatively short period of time to permit frequent measurements of performance.
5. The task has to be such that a trained subject may achieve a constant level of performance which will not increase with further practice.

In order to meet these requirements the Conceptual Reasoning Test was devised for use in this experiment. This test consists of 32 small wooden blocks having the following five dichotomous characteristics:

1. Large.........Small
2. Tall..........Short
3. Round.........Square
4. Hollow........Solid
5. Numbered......Lettered

Half, or 16, of the blocks are similar in at least one characteristic. For instance, half of the blocks are round, half are square, half are tall, half are short, half are numbered, half are lettered, etc.

Eight of the blocks are similar in at least two characteristics. That is, eight of them may be classified as tall-hollow, square-short, or numbered-large, etc.

Four of the blocks are similar in at least three characteristics--for instance, short-solid-numbered, or tall-square-small.

Two of the blocks are similar in four characteristics.

None of the blocks are similar in all characteristics.

A photograph of the test material may be found in the Appendix (Fig. 17). The blocks are colored bright yellow with numbers and letters in black, large enough to be read with ease.

Essentially the problem faced by the subject in this experiment is to select 7 of the 32 blocks having a specified number of characteristics in common with a model block. It is the subject's task to determine these common characteristics with the fewest possible errors. On the basis of extensive preliminary experimentation with this test, it was decided to use those problems involving similarity of only two characteristics, such as tall-hollow, short-square, round-numbered, etc. There are 40 of these dual classifications that may be determined for the 32 blocks. The examiner is provided with recording sheets listing the 40 problems with space provided to note the time taken and the number of errors made in solving each problem. A sample recording sheet is reproduced in Figure 18 of the Appendix.

The exact sequence in the solution of a two-category problem as used in this investigation might be as follows:

The examiner randomly selects a problem from the 40 listed on the recording sheets. For example, tall-hollow might be the dual classification which the subject is required to discover. The examiner places a tall-hollow-round-numbered-large block before the subject. The subject is required to determine which 7 of the remaining 31 blocks have the two desired characteristics in common with the model block. The model block in itself gives very little information concerning the correct solution to the problem. For instance, in this example, in addition to being tall and hollow, the model block is also round, numbered, and large. The correct solution may involve any combination of these five variables. After each choice the examiner informs the subject if he has made an error in his selection. The subjects have previously been instructed to proceed with the solution to the problems by means of the process of elimination, that is, excluding one variable at a time until the correct pair has been determined. In the case of the example, in which the correct solution involves tallness and hollowness in common with the model block, the subject's first selection might be a tall-hollow-round-numbered-small block. In this case, the first selection is identical with the model block with the exception of one characteristic, that of being small instead of large. In other words, the subject forms a hypothesis that a portion of the correct solution to the problem involves largeness. His selection is a test of this hypothesis. Because the block selected by the subject is also tall and hollow, this first choice is correct. Since this first selected block is small and the model block is large, the subject may reject his hypothesis that largeness is a part of the solution and eliminate this variable from further consideration. In order to exclude another variable, the subject next selects a block that is identical to the model, again with the exception of one characteristic. This trial the subject may select a tall-hollow-square-numbered (large or small) block. He will be testing the hypothesis that the correct solution involves the block being round. He is informed by the examiner that this selection is also correct. On the basis of this information the subject can reject his hypothesis and conclude that being round or square is not part of the solution. As the result of the first two selections the subject has determined that the correct solution must include two of the three variables: tall, hollow, and numberedness. The subject's third selection might be a tall-hollow-lettered (large or small, round or square) block. He will be testing the hypothesis that being numbered is one of the correct variables. In this case the examiner would inform him that the third selection was correct and the subject could discount the variable of numberedness. By the process of elimination the subject has tested and rejected hypotheses concerning three of the five variables. Since only tallness and hollowness remain, they by necessity have to constitute the correct solution to the problem and the subject merely selects the remaining four tall-hollow blocks.

In the above example, all of the subject's selections were correct. We might, for further clarification, consider an example in which the subject is informed that a selection is wrong. Let us assume that the correct solution to a problem is the pair of characteristics, numberedness and largeness. The model block placed before the subject is numbered-large-square-solid-short. The subject, wishing to test the hypothesis that numberedness is part of the solution, selects a block which is identical to the model with the exception of being lettered rather than numbered. He is informed by the examiner that this first selection is incorrect. Thus, the subject must accept the hypothesis that being numbered is one member of the pair of characteristics he is trying to discover. Therefore, all subsequent choices should be numbered blocks. The subject's second selection might be a numbered-large-square-solid-tall block. This block differs from the model in being tall rather than short. This selection is declared correct by the examinor. The subject can now conclude that tallness and shortness are irrelevant to the correct solution. For the third selection the subject picks out a numbered-square-solid-small (tall or short) block to test the hypothesis that largeness is the second member of the pair of variables demanded by the correct solution to the problem. He is informed by the examiner that this third choice is incorrect. The subject may deduce from this that largeness is a portion of the correct solution to the problem. Since he discovered from his first selection that numberedness was also required, he has now obtained sufficient information to inform him that the correct solution is the pair of variables, numberedness and largeness. He then selects the remaining four blocks having these characteristics.

If the subject follows a systematic and logical thought pattern, all problems can be solved with a minimum of seven or a maximum of nine selections. The subject can maintain a clear and logical thought pattern and still make two "wrong" selections. These, however, are informative errors. These two "wrong" selections offer information to the subject regarding the correct pair of characteristics which, if properly utilized, will determine his future selections. All errors exceeding two are noninformative and may be classified as actual errors. For example, the subject makes a selection not congruent with information he has obtained from previous selections, or he makes a selection which does not furnish him with useful information to determine additional choices. If the subject fails to reason correctly or to use clear logic, his performance degenerates into a strictly trial and error procedure; and the possibility of his selecting the correct blocks for solving a given problem is approximately one in four with each selection.

Instructions. After a demonstration of the nature of the test, and at intervals throughout the training period, the following instructions were read to the subjects:

> The best procedure for making a good score on this test is to work as rapidly and as accurately as you can and still not make more than two errors on any one problem. To do this it is necessary that you keep your thinking straight. The actual movements in picking up the blocks and the time required for this are of minor importance. In order to make a good score in both time and accuracy (not more than two errors for each problem) it is necessary that you proceed systematically and utilize the information given you as the result of each selection. This requires that you remain alert and reason correctly with each choice. In this way you will not only maintain accuracy but also will be able to solve the problems in a short period of time.
>
> You will continue to work on each problem until you have solved it correctly or have taken more than two minutes on one problem, at which time the examiner will stop you and present you with the next problem.
>
> The object is for you to maintain your accuracy and time per problem at the maximum level.

Scoring. The subject's performance was scored in terms of both time and accuracy. The examiner started a stopwatch at the time he placed the model block before the subject. The total time was recorded after the subject had selected, and placed in a group, all of the eight blocks having the desired pair of characteristics for that particular problem. The total number of wrong choices was also noted.

Procedure

Pre-Experimental Training. To prevent the effects of hypoxia from being camouflaged by an improvement in performance as a result of further practice, a pre-experimental training period was required.

The ten subjects were divided into pairs, one member acting as examiner and the other as subject. Their roles were reversed at specified intervals. The same pairs of subjects were maintained throughout the experiment.

The subjects were instructed in the nature of the Conceptual Reasoning Test and were given demonstrations as to the proper method of procedure in solving the problems. The training period continued for approximately three hours a day for ten days. After the first hour, a period of merely becoming familiar with the task, a continuous record was made of each subject's performance. The criterion for the cessation of practice was that the subject should solve 80 consecutive problems with only chance differences existing in the mean time for any group of 20 consecutive problems. A graphic record was kept of each subject's progress so that it was possible to determine with ease when the subject was reaching a constant level of performance. Figure 2 is offered as a typical example of the learning curve for this task.

An analysis of variance was conducted on the time scores obtained

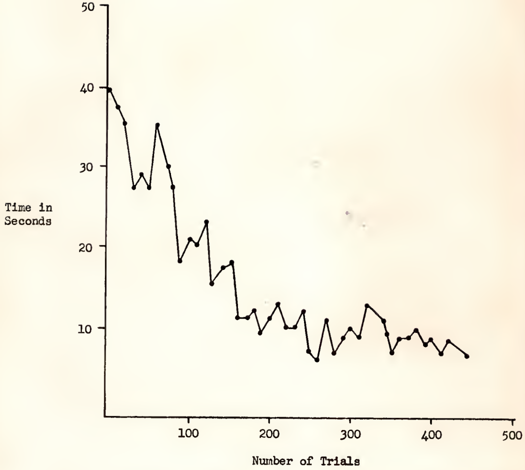


Fig. 2.--Pre-experimental practice curve. Each point represents the mean time for each group of 10 successive trials.

from each subject's mean performance for each succeeding group of 20 problems in the final series of 80 trials. These data are presented in Table 1.

Table 1

Analysis of Variance on Final Training Series for Each Subject

Subject	$\frac{sw^2}{sb^2}$	F	P
A	1644.10/25.45	2.55	> .05
B	1239.85/43.04	1.14	> .05
C	914.30/11.25	3.21	> .05
D	1857.00/10.55	6.94	> .05
E	1850.10/120.70	1.65	> .05
F	2762.25/30.14	3.62	> .05
G	1140.95/78.04	1.73	> .05
H	913.30/14.65	2.46	> .05
I	2033.75/21.14	3.80	> .05
J	2862.25/117.74	1.04	> .05

$n_1 = 76$
$n_2 = 3$

The F ratios obtained indicate that the differences in mean performance can be accounted for by chance fluctuations. Thus, there was no apparent improvement as a result of further practice during the final 80 trials.

In order to provide a reference point from which deviations from optimum performance might be evaluated, the time and standard deviation were computed for each subject's last 40 practice trials. These data are given in Table 2.

Table 2

Performance Measures of Final Training Series

Subject	Mean Time in Seconds	SD
A	19.55	3.93
B	20.05	3.20
C	16.20	3.30
D	17.20	4.45
E	17.73	4.25
F	16.80	5.03
G	16.03	3.38
H	12.93	2.83
I	18.35	4.70
J	19.15	5.00

Although there are 40 different possible combinations of paired variables in the Conceptual Reasoning Test, there are actually four different types of problems.

1. Twelve problems in which the dichotomous variables of size, shape, or height are paired.
2. Twelve problems in which size, shape, or height forms one member of the pair and hollow or solid makes up the second member of the pair.
3. Twelve problems in which size, shape, or height is combined with either number or letter.
4. Four problems from the pairing of letter, hollow, number, and solid.

On the basis of the group performance on the last 80 trials of the pre-experimental series, the difficulty level of these four types of problems was determined. This information is indicated in Table 3.

Table 3

Problem Difficulty of Conceptual Reasoning Test

Type	Mean Time in Seconds	SD
1	14.44	3.78
2	17.78	4.26
3	19.79	4.62
4	20.85	4.70

The data in the above table indicate that there is a slight difference in difficulty of the various problems making up the Conceptual Reasoning Test. On the basis of the data available in this preliminary work, it does not seem advisable to speculate on the differences in difficulty of the four types of problems as a function of their degree of concreteness or abstractness. Considering the investigations by Heidbreder (29), Goldstein (23), and others (27, 56), it might be a sound hypothesis to state that large, square, and tall are more concrete aspects of the stimuli than letter or number, and hence problems involving these qualities are more easily solved. However, the explanation in this particular case may be that it was merely more difficult perceptually to discriminate between letters, numbers, hollowness, and solidness than the other variables.

To reach a valid conclusion regarding the problem difficulty, it would be necessary to systematically vary the characteristics of the blocks so that in terms of sensory quality it would be equally as difficult to discriminate a numbered and a lettered block as it is to differentiate between a large and a small block. Since such an investigation was not the intent of the present research, the only requirement concerning the block characteristics was that the differences be sufficiently great so that even under conditions of impaired visual function the discriminations could be made with ease. From observations of the subjects and from their comments during the experiment, this requirement was apparently satisfied in the design of the test blocks.

A second factor which would contribute to the difficulty level of the four types of problems is the prescribed procedure for solution established during training. That is, all subjects were trained to test for the correctness of each of the concepts in a definite order. The first hypothesis to be tested was size of the block as one of the pair of concepts making up the correct solution. The remaining concepts were tested in the order of shape, height, hollow-solid, and finally number-letter. As a result of this procedure those problems involving shape and size as the correct solution would necessarily be less difficult than those problems involving number and letter. In the former case the solution would be discovered with the first two trials while in the latter case the subject would be required to remember what the solution "was not" while seeking to discover the correct pair of concepts. This procedure was initiated to insure a uniform method of solution by all subjects.

Inasmuch as a slight difference in difficulty of the four types of problems was anticipated, they were presented to the subjects in random order which did not permit a sequence of any one type problem.

Experimental Situation. An LPR-2 type decompression chamber was used in this research. This is quite an elaborate piece of apparatus in which conditions of very high altitudes can be simulated. Not only can the barometric pressure be controlled rather accurately, but facilities are available for cooling, heating, and ventilating. A picture of the apparatus with some of the subjects may be seen in Appendix (Fig. 15).

The pairs of subjects were seated at desks opposite each other in the chamber, the examiners on one side and the subjects on the other. The examiners wore demand-regulator type oxygen masks throughout each experimental session. The same type oxygen masks were available for the subjects when they became unconscious or in case of an emergency. In addition to those actually participating in the experiment, the present investigator and a Navy corpsman, trained in first aid, were present at all times. Observers, in radio communication with the corpsman, were stationed outside the chamber to watch all subjects carefully for signs of collapse or unusual symptoms. A physician was alerted and available for immediate service at all times during the periods at altitude.

Experimental Schedule. There were six experimental sessions of approximately two hours and nine minutes each. However, the first session was to acquaint the subjects with the procedure, establish a smooth mode of operation, and relieve general anxiety that might influence performance in the actual experimental sessions. The results of this initial altitude run at 12,000 feet are not included in the data.

The simulated altitudes attained and their order of occurrence were as follows:

Session 1	13,000 feet
Session 2	16,000 feet
Session 3	Sea level
Session 4	18,000 feet
Session 5	17,000 feet

Actually the sea level session was at an altitude of approximately 150 feet. In order to keep conditions as constant as possible with the other sessions and so as not to prejudice the subjects, the chamber was initially taken up to 10,000 feet but immediately dropped down to 150 feet simulated altitude. With this procedure it was necessary to keep all pumps and ventilating equipment in operation so that noise and other variables were comparable with conditions at the other altitudes. That this ruse was successful was indicated by the fact that although the subjects could detect from subjective symptoms that they were not as high as they had been in the previous session they guessed their approximate altitude to be from 8,000 to 12,000 feet.

The sea level session acted as a control for variables extraneous to the effect of degree and duration of hypoxia. The modification of behavior as a function of the independent variable was measured by utilizing each subject as his own control. That is, the performance of each individual at a given degree or duration of stress was compared with that same individual's performance at other degrees and durations of stress.

The pairs of subjects were divided into two groups labeled A and B. Group A acted as examiners in the morning and as subjects in the afternoon of an experimental day. The procedure was reversed for Group B. During the following experimental session, the order of procedure for the two groups was changed so that Group B acted as examiners in the morning and as subjects in the afternoon. Because of previous operational commitments of the chamber, minor ailments of the subjects, and the advisability of spacing the exposure to hypoxia, the experimental sessions were spread over a period of 14 days.

As mentioned previously, the total time in the chamber for each session was approximately two hours and nine minutes. This period was divided into seven equal work periods which we shall refer to as units within experimental sessions. The activity for each unit from the time of entering the chamber may be seen in Figure 3.

Since the subjects were to be confined in an unpleasant environment for such long periods, it seemed advisable to include an additional activity which might be alternated with the Conceptual Reasoning Test.

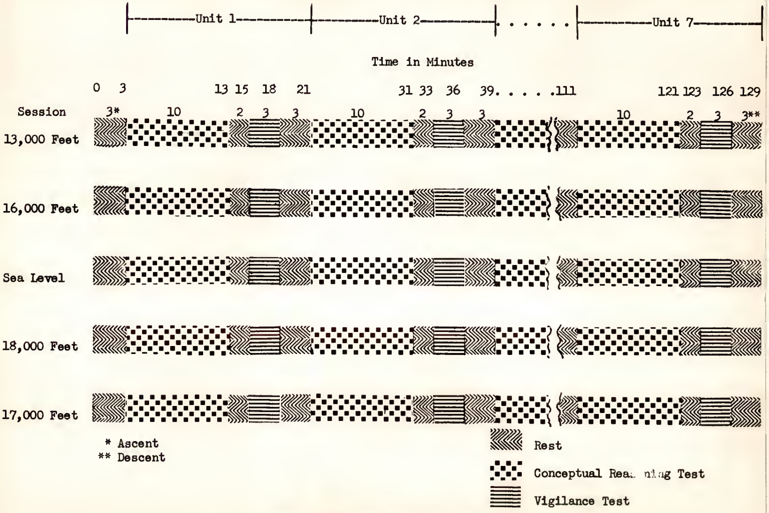


Fig. 3.--Experimental Schedule

This procedure seemed advisable to avoid monotony and boredom and to aid in maintaining motivation toward the experiment. A group of seven vigilance tests was devised, each consisting of a series of two-digit numbers. The subjects were required to underline all sequences of three or more odd-numbered digits. The data derived from this material, not pertinent to the present problem, will be reported in a future publication.

The same amount of time was taken to reach altitude for each session. The initial period of ascending to altitude was used by the subjects as a "warming up" period for the Conceptual Reasoning Test. The experimenter kept a careful check on the time for starting and stopping each activity within all units.

The subjects were instructed to continue working until the session was complete or until they felt themselves on the verge of unconsciousness. From previous orientation they were intellectually acquainted with the symptoms but had never actually experienced unconsciousness resulting from hypoxia. Fortunately for the purposes of the experiment, the men cooperated in a commendatory manner. All subjects but one, who maintained some degree of performance throughout each session, worked at the assigned tasks until they became unconscious or were completely incapacitated. The decision to cease work if the subject did not completely collapse was at the discretion of the subject himself, the experimenter, or the corpsman present in the chamber. Of course, under severe hypoxic stress there were numerous occasions in which the subject lacked the insight to recognize his own symptoms of imminent collapse.

The subjects were provided with pencil and paper and asked to record all subjective symptoms, both physiological and psychological, that they experienced during the sessions. In addition, if they had lost consciousness during a particular session, upon recovery they were asked to record all that they remembered of the events immediately preceding the collapse.

Reliability and Validity

The reliability of the Conceptual Reasoning Test was assured by the period of prior training and the criterion for the cessation of practice. However, a reliability coefficient was calculated for the group by an analysis of variance technique. This procedure for determining reliability was proposed by Hoyt (33) and later amplified by Hoyt and Stunkard (34). Utilizing this method, the final 80 trials of the training series were grouped into four sections of 20 consecutive problems and an analysis of variance was used to test these data. The results are presented in Table 4.

The coefficient of reliability may be expressed as:

$$\frac{\text{Mean Square between Individuals - Residual}}{\text{Mean Square between Individuals}} = \frac{7615.2256 - 156.0841}{7615.2256} = .9795$$

As one might expect from our procedure the obtained reliability coefficient is sufficiently large to allow us to place confidence in the consistency of performance measurements obtained with this instrument.

The validity of the Conceptual Reasoning Test is based upon

Table 4

Computation of the Coefficient of Reliability
by Analysis of Variance

Source of Variation	d.f.	Sum of Squares	Mean Square
Total	39	77990.78	
Between Sections	3	5239.48	1746.4933
Between Individuals	9	68537.03	7615.2256
Residual	27	4214.27	156.0841

logical grounds rather than as the result of a correlation of the present test results with an external criterion. In fact, in this situation the criterion upon which validity is based is performance upon the instrument itself. That is, the goal or purpose is to measure performance with this instrument under various hypoxic conditions rather than to predict performance in some other task. Since we have demonstrated the test to be a reliable measure, logically it is a valid measure of itself. In such a situation the index of reliability, .99—the square root of the reliability coefficient, can be taken as the validity coefficient (50).

Although the test is apparently valid in terms of the purposes for which it was constructed, we have referred to this instrument as a Conceptual Reasoning Test. Hence we may be obligated to show that conceptual reasoning is required for successful performance, although this is not essential to the problems proposed by this research.

A review of the description of the test will demonstrate that the differentiating characteristics of the test objects are generally accepted as concepts: largeness, smallness, roundness, tallness, etc. Reasoning or mentally manipulating these concepts to determine relationships is evident from previous descriptions of successful solutions.

External support for this type instrument as a conceptual reasoning test is provided by the works of Vigotsky (56), Goldstein (23), Scheerer (24), and Hanfmann and Kasánin (27), who have developed tests of this nature which have come to be accepted as measures of conceptual reasoning.

The Block Criterion

Since we have postulated the appearance of response blocks in performance under stress, it will be necessary to establish a criterion for their detection.

The accuracy with which we detect blocks will be determined by the performance being investigated and the methods of measurement. Blocks could occur which would not interfere with the behavior being evaluated or during intervals of time which were not recorded in our measurements. For instance, in the Conceptual Reasoning Test, the subject was not required to perform during the interval in which his responses to the previous task were being recorded or while the examiner was selecting and presenting the model for the next problem. In addition, it is possible that this interval between problems, even though only a few seconds, served as a rest period and influenced in some manner the appearance of blocks in the execution of the following problem. For these reasons a response block must be operationally defined in terms of the task and the methods of measurement.

With a simple task like color naming, in which the exact length of a block is more easily determined, it is quite conceivable that one could empirically define a response block. However, in the present research, utilizing a complex task, the amplitude of response blocks cannot be determined since the actual time elapsing during the block is imbedded in the total time required to solve the problem. The presence of a block must be inferred from the atypical response time.

For instance, let us suppose that for a given individual the mean time required to solve the Conceptual Reasoning Test problems is 15 seconds with a standard deviation of 3 seconds based upon his performance during the final series of practice trials. In a hypoxic stress situation this individual requires the following time intervals to solve a series of problems:

14 seconds
17 "
15 "
48 "
18 "
13 "
37 "
12 "
16 "

In this series we have two responses which are quite deviant from those which precede and follow them. Apparently, something happened to the behavior during the intervals required for the solution of these two problems. One cannot determine exactly what occurred in the subject's behavior during these periods, for there are numerous possibilities that might account for these atypical responses:

1. The subject may have methodically followed all the logical steps necessary for successful solution but at a much slower rate than that of which he was capable at other times.
2. There may have been a single period of time lasting several seconds during which he was unable to respond.
3. There may have been several very short periods of time during which he was unable to respond.

It was not feasible with the present measuring instrument to differentiate between these various possibilities. Since the subject continues to work until he has achieved a successful solution to each problem, the total time included in the atypical response cannot be entirely taken up by the actual blocking effect. Therefore, we cannot specify the exact duration of these individual periods of impaired performance, which may increase in number and/or amplitude with hypoxic stress. It is merely inferred that there is a decrement of efficiency during these atypical response periods, and it is these total periods which we refer to as response blocks.

We must now define the limits beyond which a response will be considered atypical. Stable behavior was demonstrated during the final practice series with only slight variation from trial to trial. It is reasonable to suppose that under stress the performance would deviate from this norm in a positive direction. Since we are primarily interested in only one-half of the normal curve, we have adopted for the block criterion any response which exceeds the mean plus 3.09 standard deviation units, which, according to the normal probability table, provides a .001 level of confidence (36).

Table 5

Block Criterion for Each Subject

Subject	Mean Time in Seconds	SD	Mean + 3.09 SD
A	19.55	3.93	31.69
B	20.05	3.20	29.94
C	16.20	3.30	26.40
D	17.20	4.45	30.95
E	17.73	4.25	30.86
F	16.80	5.03	32.34
G	16.03	3.38	26.47
H	12.93	2.83	21.67
I	18.35	4.70	32.87
J	19.15	5.00	34.60

This particular criterion was selected for the reason that it is sufficiently large so that responses exceeding this amount could without question be considered blocks. This, of course, has a disadvantage in the fact that blocks may also have occurred in responses consuming less time than that demanded by this limit. However, if the criterion were less rigorous we would be open to the criticism that we had considered as blocks those responses which were merely normal variations in behavior.

Each subject's mean, standard deviation, and that point which represents plus 3.09 standard deviation units from his mean performance on the last 40 practice trials are indicated in Table 5. All responses exceeding the criterion for each subject will be considered as a block.

In the next section of this paper we will consider the methods of analysis used in the evaluation of the data and the results obtained from the procedure indicated above.

CHAPTER IV

ANALYSIS AND RESULTS

Introduction

As indicated previously, the goal of this research was to test several hypotheses regarding the decrement of performance in a conceptual reasoning task under different degrees and durations of hypoxic stress.

This analysis will be presented in three sections. The purpose of the first section is to determine if there is a loss of performance efficiency in the Conceputal Reasoning Test under the specified experimental conditions. The second section will be concerned with the blocking effect and its significance to efficiency under hypoxia. Finally, we will evaluate the manner in which the individual adjusts to continuous hypoxic stress as reflected in performance on the Conceptual Reasoning Test.

Analysis by Degree of Stress

Prior to a detailed analysis of the data, Table 6 indicates the number of observations made on the Conceptual Reasoning Test. It is quite apparent from these data that the number of responses tends to decrease with altitude. This is partially accounted for by the fact that unconsciousness appears earlier and affects a greater number of subjects as the simulated altitude is increased. Consequently, the number of

Table 6

Number of Problems Solved

Subject	Session (Altitude in Feet)					
	Sea Level	13,000	16,000	17,000	18,000	Total
A	153	143	90	101	101	588
B	120	107	90	102	78	497
C	134	144	139	135	153	705
D	126	102	57	50	60	395
E	180	144	47	36	61	468
F	159	153	54	22	41	429
G	164	147	97	106	73	587
H	169	187	84	87	71	598
I	137	117	80	20	74	428
J	116	119	112	69	112	528
Total	1458	1363	850	728	824	5223

responses for the more severe degrees of stress is less than the number recorded at lower altitudes. As indicated in the experimental schedule, each session consisted of seven equal units of work. Table 7 exhibits the number of units completed by each subject for the different sessions.

It may be noted that there is relatively little difference in the number of units completed at the higher altitudes. In fact, the number of units completed at 18,000 feet is slightly greater than the units completed at 16,000 feet. This would indicate that when the hypoxic stress becomes rather severe collapse will occur at about the same point. The situation is similar to that in which a person is made unconscious from a blow on the head. As the force of the blow is

Table 7

Units Completed by Each Subject

Subject	Session (Altitude in Feet)				
	Sea Level	13,000	16,000	17,000	18,000
A	7	7	4	5	6
B	7	7	7	7	5
C	7	7	7	7	7
D	7	7	3	4	5
E	7	7	3	3	5
F	7	7	3	2	3
G	7	7	5	6	5
H	7	7	4	5	4
I	7	7	5	3	6
J	7	7	5	5	7

increased, the greater the possibility that unconsciousness will result. However, after a critical degree of force is exceeded, unconsciousness invariably follows and any increase beyond this point does not affect the rapidity or probability of its occurrence.

The above data indicate quite clearly the extent to which the subjects suffered from hypoxia during the experimental sessions. We are now in a position to test Hypothesis I: For the task utilized in this investigation, there is a significant difference between the efficiency of performance at sea level and all other simulated altitudes in which measurements were obtained.

It is recognized that to be statistically precise, the hypotheses should be stated in the null fashion. Then, if rejected, the obtained difference in our measures could be attributed to the independent variable. However, for clarity of exposition, the hypotheses are stated in a positive manner.

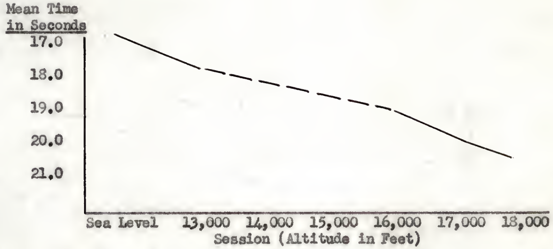


Fig. 4. Mean Time per Problem by Session

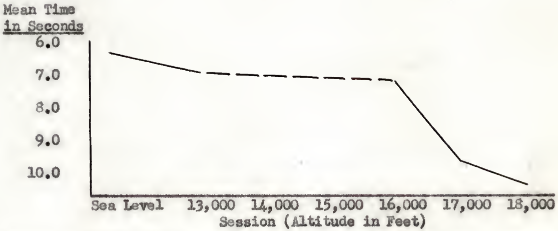


Fig. 5. Variability of Performance by Session

Figure 4 indicates in graphic form the mean time required to solve the Conceptual Reasoning Test problems for each session.

Figure 5 indicates the variability of performance on the Conceptual Reasoning Test as a function of degree of stress or simulated altitude. The points are plotted from the standard deviation derived from the group data for all sessions.

Figures 4 and 5 evidence a progressive increase in mean time and variability as degree of stress is increased. An analysis of the difference in performance at the various altitudes was conducted by means of the "t" test. The results of this analysis are presented in Table 8.

Table 8

Performance Measures by Session

Session (Altitude in Feet)	Mean	SE_M	SD	"t" Values				
				Sea Level	13,000	16,000	17,000	18,000
Sea Level	17.12	.17	6.46	. . .	2.44	6.03	6.95	8.23
13,000	17.78	.19	6.99	. . .	. . .	3.85	5.13	6.38
16,000	19.05	.26	7.41	. . .	. . .	. . .	1.77	2.91
17,000	19.83	.35	9.57	. . .	. . .	. . .	. . .	1.02
18,000	20.33	.34	9.93	. . .	. . .	. . .	. . .	. . .

An inspection of the "t" values in Table 8 indicates a difference in performance between sea level and 13,000 feet which is significant at the .05 level. The differences between sea level performance and all other degrees of stress are significant at greater than the .001 level. These data permit the acceptance of our initial hypothesis. We find a decrement in performance and greater variability during all experimental sessions exceeding sea level.

The Blocking Effect

Frequency of Blocks by Degree of Stress. We have demonstrated that there is a significant decrement in performance on the Conceptual Reasoning Test as a function of degree of hypoxic stress. We are now prepared to evaluate the relationship between the block effect and hypoxic stress. This will be accomplished in part by testing Hypothesis II: There is a significant increase in the frequency of blocks with degree of stress.

In accordance with our criterion, all responses which exceeded plus 3.09 standard deviations from individual mean performance were considered as block responses. The frequency with which these appeared during each experimental session may be noted in Table 9.

These data portray a gradual increase in the percentage of blocks as simulated altitude is increased from sea level to 17,000 feet. It may be noted that a greater percentage of block responses occurs at 17,000 than at 18,000 feet. This would indicate that the percentage of blocks may increase with degree of stress up to a given point, beyond which we find chance differences. This point may mark the limit of the adequacy of the compensatory mechanisms. In order to determine the veracity of this explanation it would be necessary to extend our measurements to greater altitude.

Table 9

Relationship of Blocks and Errors to Degree of Stress

	Session (Altitude in Feet)				
	Sea Level	13,000	16,000	17,000	18,000
Number of responses	1458	1363	850	728	824
Number of blocks	59	71	78	88	92
Percentage of blocks	4.05	5.21	9.18	12.09	11.16
Number of errors	63	85	45	48	64
Percentage of errors	4.32	6.24	5.30	6.59	7.77

A 2 X 2 chi-square analysis was performed to determine if there were a significant increase in the frequency of blocks with altitude (49). As one would anticipate from an inspection of the data, the analysis showed this increase to be significant beyond the .001 level.

On the basis of these results we may accept Hypothesis II: There is a significant increase in the percentage of block responses as degree of stress is increased.

Table 9 also portrays the relationship of errors to degree of stress. The data show an increase in the percentage of errors as we move from sea level to other altitudes but only slight increases in the percentage of errors between altitudes.

Frequency of Blocks by Phase of Stress. Our analysis to this point has consisted of an evaluation of the decrement in performance as a function of degree of stress. We have considered only the total performance at the different altitudes and have not attempted to evaluate the subjects' performance during consecutive periods at the same altitude. Since all the subjects did not collapse at the same point, it was impossible to compare performance under continuous stress by means of the temporally equal units of work in each experimental session. For instance, the more stable subjects might continue to perform at a given degree of stress through Unit 7 while the less stable subjects collapsed during Unit 4 or 5. Thus a comparison of performance decrement for the seven units would have very little meaning. For this reason a procedure had to be devised in order to make comparable the performance of the different individuals at the same relative point in their decline. This was accomplished by dividing all the responses occurring during the period from normality to unconsciousness into five phases, each phase containing approximately the same number of responses. In this manner an individual's performance in any one of the phases at a given altitude could be compared with his proficiency during any other phase at the same altitude. Further, this procedure made possible the combining of the individual data so as to permit an evaluation of the group decrement in performance. The selection of five phases, rather than another number, was largely an arbitrary choice. However, it was primarily determined by the frequency of responses for those individuals who collapsed relatively early at the higher altitudes. In other words, the total number of responses in such cases was so limited that a division into smaller segments would be quite unstable. On the other hand, using a lesser number of phases would not permit as adequate an evaluation of the changes in activity occurring during any single session. Considering all factors, the selection of five phases seemed the best choice for this particular situation.

The presentation of data in Table 10 indicates the relationship between the percentage of block responses and phase of decline under hypoxia.

These data show the tendency for the percentage of block responses to increase with duration or phase of stress.

It may also be noted that as altitude is increased the percentage of block responses tends to be greater for any given phase. In other words, an increase in the percentage of blocks appears at earlier phases as one ascends in altitude. For instance, although the total percentage of block responses is slightly greater for 17,000 than for 18,000 feet, the percentage of blocks is greater during Phases 1 and 2 at the higher altitude.

Although at several points a particular phase does not show a greater percentage of block responses than the preceding phase, it is clear that the trend of the data permits the acceptance of Hypothesis III: There is a significant increase in the frequency of blocks with duration of stress. Table 11 indicates the relationship of percentage of errors to phase of performance for all altitudes combined.

Table 10

Relationship of Blocks to Phase by Altitude

	Phase				
	1	2	3	4	5
			Sea Level		
Number of responses	295	293	292	291	287
Number of blocks	18	11	10	13	8
Percentage of blocks	6.10	3.75	3.42	4.47	2.79
			13,000 Feet		
Number of responses	277	277	272	270	267
Number of blocks	10	9	11	19	23
Percentage of blocks	2.61	3.21	4.04	7.04	8.61
			16,000 Feet		
Number of responses	173	173	169	169	166
Number of blocks	7	8	12	21	30
Percentage of blocks	4.05	4.62	7.10	12.43	18.07
			17,000 Feet		
Number of responses	150	147	144	144	143
Number of blocks	9	10	21	20	28
Percentage of blocks	6.00	6.80	14.58	13.89	19.58
			18,000 Feet		
Number of responses	170	166	165	162	161
Number of blocks	16	13	15	21	29
Percentage of blocks	9.41	7.83	9.09	12.96	18.01

Table 11

Relationship of Errors to Phase of Performance

Combined Sessions

	Phase				
	1	2	3	4	5
Number of responses	1065	1056	1042	1036	1024
Number of errors	58	77	85	90	97
Percentage of errors	5.45	7.29	8.16	8.69	9.47

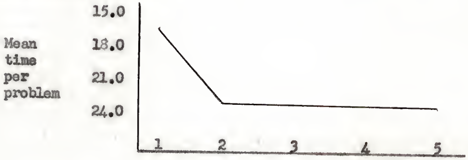
These data portray a gradual increase in percentage of errors with increasing duration under stress. It is to be expected that errors would occur in block responses and hence increase in a similar manner with phase of stress.

Stability under Stress

We have demonstrated that there is a significant decrement in the Conceptual Reasoning Test under hypoxic stress. Further, we have shown the block effect to be present in this task for both degree and duration of stress. We have defined a block as a temporary inability to respond in some specified manner. Since we have no absolute measure of the temporal interval occupied by the block, its presence must be inferred from variation in the performance of the task. Since the subject performs at a superior level of efficiency both before and after the response exceeding the criterion limits, it appears justified to assume that during this period the subject was temporarily unable to respond.

As mentioned previously, it is felt that these responses enable the organism to maintain a constant level of performance under stress. We will evaluate this proposal by an analysis simultaneously presenting the data including blocks and the results when the block responses are excluded. In this manner we will test Hypothesis IV: The relationship between the decrement of performance and continuous hypoxic stress is saltatory.

In accordance with our previous discussion, it is felt that there exists a saltatory relationship between duration of stress and behavior decrement. It is anticipated that this relationship will appear similar to the following diagram:



Phase of Performance

As is apparent from the above, it is assumed that we will find an initial decline in performance followed by a period of uniform behavior which continues until collapse. In order to accept our hypothesis, the following relationships will have to be present:

1. If significant differences in performance are present, they will exist between Phase 1 and any or all other phases.

2. Only chance differences in performance will exist between Phases 2, 3, 4, and 5. In other words, we will have uniform behavior during the final four phases of performance.

The data obtained from each experimental session or degree of stress will be evaluated separately. The following graphs present simultaneously the complete data for all sessions, as well as the data with block responses excluded so as to demonstrate their effect upon the total performance. Also included are tabular presentations of the data from which the points of the graphs were plotted and "t" values obtained.

Figure 6, which presents the data collected during the sea level session, indicates a constancy of performance throughout the experimental period. This situation facilitates analysis considerably since it does not require an elaborate statistical treatment of the data to filter out the effects of fatigue, monotony, and other contaminating factors. Elimination of the block responses does not alter the trend of the data but merely decreases the mean time and variability for each session. The "t" values show no differences significantly greater than chance between the performance during any of the five phases of this session.

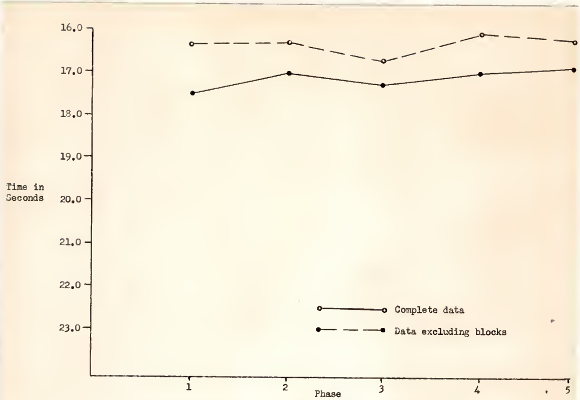


Fig. 6.--Mean Time per Problem by Phase at Sea Level

Table 12

Performance Measures by Phase at Sea Level

Measure		Complete data by phase					Data excluding blocks by phase				
		1	2	3	4	5	1	2	3	4	5
N		295	293	292	291	287	277	282	282	278	279
M		17.48	17.05	17.23	16.98	16.84	16.35	16.33	16.74	16.10	16.29
SE_M		.42	.36	.35	.38	.35	.32	.30	.32	.30	.31
SD		7.32	6.24	6.05	6.49	6.10	5.36	4.96	5.35	5.02	5.22
"t" Values by Phase	1	. . .	.75	.45	.88	1.12	. . .	.05	.87	.57	.13
	2	. . .	. . .	.35	.13	.40	. . .	. . .	.93	.55	.09
	3	. . .	. . .	. . .	.49	.78	. . .	. . .	. . .	1.45	1.00
	4	. . .	. . .	. . .	. . .	.27	. . .	. . .	. . .	. . .	.43

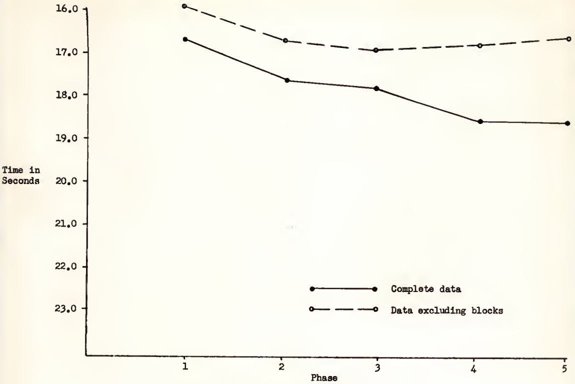


Fig. 7.—Mean Time per Problem by Phase at 13,000 Feet

Table 13

Performance Measures by Phase at 13,000 Feet

Measure		Complete data by phase					Data excluding blocks by phase				
		1	2	3	4	5	1	2	3	4	5
N		277	277	272	270	267	267	268	261	251	244
M		16.77	17.64	17.75	18.39	18.37	16.09	16.82	17.05	16.92	16.74
SE_M		.37	.42	.37	.47	.46	.31	.32	.32	.33	.33
SD		6.21	7.00	6.17	7.75	7.55	5.08	5.27	5.12	5.15	5.23
"t" Values by Phase	1	. . .	1.53	1.85	2.70	2.71	. . .	1.62	2.13	1.80	1.41
	2	. . .	. . .	.19	1.19	1.18	. . .	. . .	.51	.22	.17
	3	. . .	. . .	. . .	1.07	1.05	. . .	. . .	. . .	.28	.67
	4	. . .	. . .	. . .	. . .	.03	. . .	. . .	. . .	. . .	.38

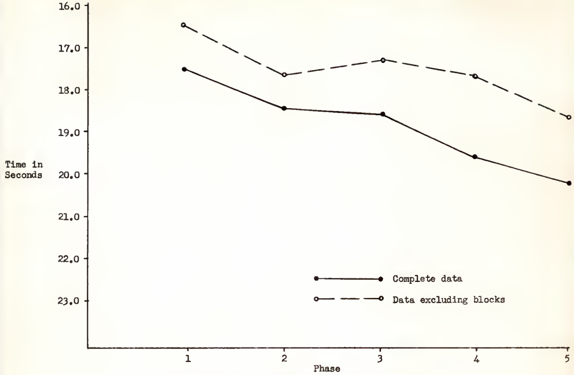


Fig. 8.—Mean Time per Problem by Phase at 16,000 Feet

Table 14

Performance Measures by Phase at 16,000 Feet

Measure		Complete data by phase					Data excluding blocks by phase				
		1	2	3	4	5	1	2	3	4	5
N		173	173	169	169	166	166	165	157	148	136
M		17.46	18.43	18.49	19.56	21.42	16.52	17.68	17.16	17.62	18.49
SE_M		.54	.44	.55	.59	.67	.39	.36	.41	.41	.50
SD		7.09	5.82	7.09	7.64	8.57	5.05	4.58	5.10	4.95	5.82
"t" Values by Phase	1	. . .	1.41	1.34	2.63	4.60	. . .	2.19	1.12	1.93	3.13
	2	. . .	. . .	.09	1.55	3.74	. . .	. . .	.95	.11	1.31
	3	. . .	. . .	. . .	1.32	3.37	. . .	. . .	. . .	.79	2.05
	4	. . .	. . .	. . .	. . .	2.09	. . .	. . .	. . .	. . .	1.34

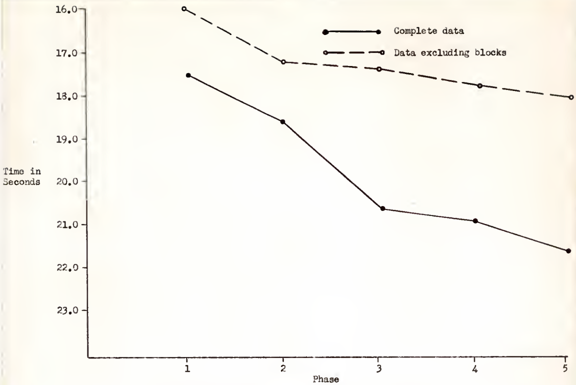


Fig. 9.--Mean Time per Problem by Phase at 17,000 Feet

Table 15

Performance Measures by Phase at 17,000 Feet

Measure		Complete data by phase					Data excluding blocks by phase				
		1	2	3	4	5	1	2	3	4	5
N		150	147	144	144	143	141	137	123	124	115
M		17.61	18.53	20.65	20.85	21.64	16.09	17.15	17.29	17.51	17.83
SE_M		.70	.60	.86	.85	.85	.43	.42	.46	.41	.47
SD		8.57	7.78	10.28	10.20	10.16	5.10	4.87	5.05	4.54	5.06
"t" Values by Phase	1	. . .	1.00	2.74	2.95	3.66	. . .	1.74	1.90	2.37	2.72
	2	. . .	. . .	2.02	2.23	2.99	. . .	. . .	.23	.61	1.08
	3	. . .	. . .	. . .	.17	.82	. . .	. . .	. . .	.35	.82
	4	. . .	. . .	. . .	. . .	.66	. . .	. . .	. . .	. . .	.52

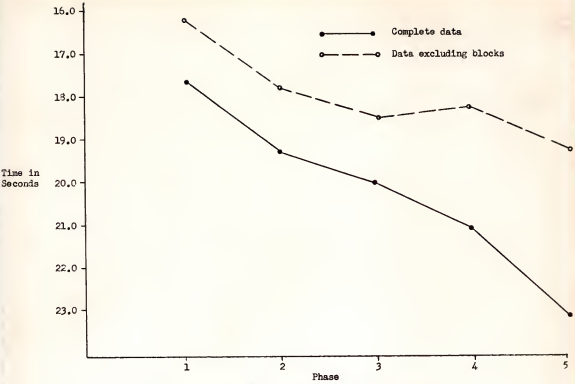


Fig. 10.—Mean Time per Problem by Phase at 18,000 Feet

Table 16

Performance Measures by Phase at 18,000 Feet

Measure		Complete data by phase					Data excluding blocks by phase				
		1	2	3	4	5	1	2	3	4	5
N		170	166	165	162	161	154	153	150	141	132
M		17.83	19.48	20.24	21.27	23.00	16.24	17.90	18.46	18.19	19.04
SE_M		.55	.64	.66	.95	.95	.41	.44	.46	.47	.48
SD		7.16	8.19	8.53	12.09	12.01	5.08	5.40	5.66	5.61	5.54
"t" Values by Phase	1	. . .	1.96	2.80	3.13	4.70	. . .	2.77	3.58	3.15	4.44
	2	. . .	. . .	.83	1.57	3.09	. . .	. . .	.89	.45	1.75
	3	. . .	. . .	. . .	.89	2.38	. . .	. . .	. . .	.41	.88
	4	. . .	. . .	. . .	. . .	1.29	. . .	. . .	. . .	. . .	1.27

Figure 7 portrays the relationship between performance for each of the five phases at a simulated altitude of 13,000 feet. The complete data show a difference in performance between Phase 1 and Phases 4 and 5, respectively, at the .01 level of significance. The data with blocks excluded show a mean difference in performance between Phase 1 and Phase 3 which is significant at the .05 level. Beyond this point proficiency remains constant or slightly improved. It should be noted also that the difference between the performance during Phase 1 and Phase 5 does not exceed chance fluctuation. In other words, there are only chance differences in the efficiency of the subjects between the first and final phases of their performance at 13,000 feet if the block responses are excluded. In both groups of data we find an initial decline in performance. In no case is the difference significant between Phase 2 and any other phase. Apparently there is an initial decline in performance which is followed by a period of relative constancy. By excluding the block responses, the trend toward constant performance is emphasized. Considering the fact that a simulated altitude of 13,000 feet is a relatively mild stress situation, one would not expect a severe decrement of performance.

Figure 8, which presents the data from the 16,000-foot session, portrays in a rather clear manner the effect of eliminating the block responses. The complete data show a decline in efficiency of performance with each phase; the data with blocks excluded show an initial decline and relatively constant performance for the remainder of the session.

In fact, the performance during Phase 3 of the latter data was slightly better than that of Phases 2 and 4. Such a situation could not exist if the decline in efficiency were continuous with duration under stress. However, we do note a "t" value of 2.05 obtained from the comparison of Phases 3 and 5, which is just barely significant at the .05 level.

Figure 9 indicates the relationship between performance and duration of stress at an altitude of 17,000 feet. The saltatory relationship is quite apparent in the block-excluded data. We find an initial decline followed by a slight but nonsignificant decline in performance. Only chance differences in performance exist between Phases 2, 3, 4, and 5. The complete data, on the other hand, show a continuing increase in mean time with each phase of performance.

Figure 10, which portrays the data collected during the highest simulated altitude, presents the saltatory nature of the decrement in performance with the greatest clarity. The complete data indicate a continuous loss of efficiency with each phase of performance under hypoxic stress. The block-excluded data, on the other hand, indicate an initial drop in proficiency from Phase 1 to Phase 2 with only chance fluctuation in performance thereafter.

It may be recalled (Table 7) that all subjects did not collapse in the higher stress sessions. One individual remained conscious throughout the three higher altitudes. The justification for including these individuals in the group analysis may be questioned since they were not at the same stage of disintegration as those individuals who did collapse.

This possibility was tested by eliminating the records of those individuals from the analysis. This did not result in a significant change in the data. It may be assumed that although these subjects did not become unconscious, their performance efficiency had suffered to an extent comparable to those individuals who did actually collapse.

It is apparent from the preceding analysis that the complete data show an increasing impairment of performance with persistence of stress. However, when those responses which include blocks are omitted from the analysis this progressive impairment does not appear. Under these conditions one finds an initial drop in proficiency followed by a relatively constant level of performance.

The data analysis fulfills the prerequisite relationship which was postulated as characterizing the saltatory decrement of performance:

1. At all altitudes in which a decrement appeared a significant difference in performance existed between Phase 1 and one or more of the following phases.
2. Only chance differences were shown to exist between the performances of the final four phases.

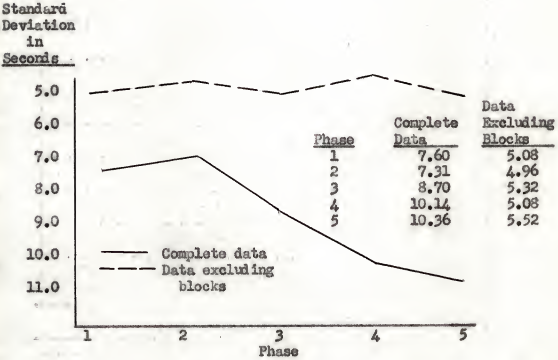
It may be recalled that we did find a significant difference existing between the mean performance during Phase 3 and Phase 5 at 16,000 feet. The probability value for the obtained difference just exceeded the .05 level of significance, which means that a difference as large as that obtained could occur by chance five times out of a hundred. Since we performed a total of 30 tests of significance in evaluating performance in the final four phases and found only this single significant value, it does not seem justifiable to reject our hypothesis on the basis of this one exception which may be attributed to chance fluctuation.

It may be noted from the preceding data that when the block responses are excluded the standard deviations remain relatively constant throughout the five phases of performance. The constancy of variability when block responses are omitted is also apparent from Figure 11, which presents the variability curves for performance during the three highest altitudes.

In our analysis we have omitted only the extreme positive deviations. If we also omit the responses which are minus 3.09 from the pre-experimental norm and draw a variability curve for all deviations from the mean, this curve is almost identical to the plot of the block-excluded data of Figure 11. This may be accounted for by the fact that only two of the subjects had any responses minus 3.09 standard deviations below their mean, and these were so few in number that the form of the variability curve was not affected.

The fact that we do find constant variability indicates that the performance remains relatively uniform throughout the various phases of stress when block responses are excluded.

The preceding analysis provides sufficient evidence to permit the acceptance of our fourth hypothesis. At all altitudes tested we find that when block responses are omitted there is an initial drop in proficiency from the level achieved during Phase 1. The "t" values of Phases 2, 3, 4, and 5 for all altitudes show no difference beyond that which one might expect by chance. Thus it seems apparent that we do have a saltatory relationship between performance and continuous hypoxic stress; i.e., an initial decrement followed by constant performance until collapse. Therefore, we accept Hypothesis IV: The relationship between the decrement of performance and continuous hypoxic stress is saltatory.



Phase	Complete Data	Data Excluding Blocks
1	7.60	5.08
2	7.31	4.96
3	8.70	5.32
4	10.14	5.08
5	10.36	5.52

Fig. 11.—Standard deviations by phase, combined altitudes of 16,000, 17,000 and 18,000 feet.

CHAPTER V

DISCUSSION

In a research endeavor dealing with the measurement of behavior under stress one is constantly faced with the problem of individual differences in susceptibility to the stress, intra-individual variation in susceptibility, and adequacy of compensatory mechanisms to operate under stress. These factors are quite pronounced in the present experiment. Reference to Table 7 indicates that one individual remained conscious throughout all experimental sessions, several subjects collapsed relatively early in the 16,000-foot session, and some performed more efficiently at 18,000 feet than at 17,000 feet. These inter-and intra-individual differences may be better comprehended by a brief presentation of the observations made of the subjects' behavior under stress.

Observations

As has been indicated, all subjects were provided with paper and pencil and requested to record physiological and psychological changes noted during the course of the experiment. Opportunity was provided for this during the rest periods. No attempt will be made to reproduce all of the subjective complaints of each individual as this would be quite repetitious.

The most frequently cited physical symptoms were as follows: dizziness, motor tremor, nausea, dimming of vision, tingling sensations in the extremities, cyanosis, and headache. The most frequently mentioned and observed psychological symptoms were hyperactivity, depression, sullenness, irritability, euphoria, and lassitude.

The manner in which the subject lost consciousness and the extent of his collapse at the time he ceased test performance undoubtedly influenced the findings to some extent. The following account of the general behavior pattern of the various subjects will demonstrate that each had not reached the same point of disintegration at the time of collapse.

Subject A. This subject collapsed during each of the three highest altitudes. In each case he became quite hyperactive and almost manic. The subject would brag about how well he was doing on the task, express to all how good he was feeling, and would request that the chamber be taken up higher. His movements were rapid and fairly well coordinated. His actions would gradually increase in intensity until he suddenly collapsed completely. In the midst of performing the task, his head would fall forward, and he had to be supported so as not to fall from the chair. During the 17,000-foot session, he dropped a pencil to the floor, and it rolled away from his desk. He got up to retrieve the pencil, walked several steps, stooped over and picked it up, and returned to his chair. Just as he was seated, he collapsed and required oxygen. Apparently the slight, extra exertion required to get the pencil was sufficient to bring about unconsciousness. He recovered with a severe headache which lasted approximately thirty minutes.

Subject B. This subject reacted to hypoxia as if intoxicated. The symptoms were easily noted in his motor coordination and personality changes. He tended to become euphoric and at some times rather vulgar. He became unconscious on two occasions, but during the 17,000-foot session his behavior became so disorganized that he could not, or would not, continue with the task. Since he was beginning to interfere with the activities of the other subjects he was given oxygen. Immediately thereafter he became quite calm and proceeded to read a book during the remainder of the experimental period.

Subject C. This individual remained conscious throughout all test sessions. Even though his performance did show a decrement under stress and was congruent with our general findings, he never reached the final end point of collapse. Physical symptoms of hypoxia were present. There were no pronounced psychological changes in his behavior.

Subject D. This subject collapsed in all sessions above sea level. The general pattern of his disintegration was quite similar in all cases. During the early period of stress he had a tendency to be irritable, self-critical, and to work with considerable effort. Gradually, as stress continued, he became talkative and generally euphoric. In all cases his collapse started with silly giggling and developed into hysterical laughter, at which time the oxygen mask was put on him. In these cases he would struggle against the mask, and it would require two people to get the mask properly adjusted. After a few seconds of oxygen he would recover completely. When questioned regarding his previous behavior he could not recall what it was that brought about his hysterical laughter.

Subject E. This subject collapsed rather early during the three highest simulated altitudes. His disintegration was rather unspectacular in that he showed the common overt signs of hypoxia (pallor, motor tremor, and cyanosis) relatively early and continued in this state until collapse. He did not become completely unconscious but could no longer perform.

Subject F. This man became unconscious in all sessions except at sea level. His pattern of disintegration was quite uniform in all cases. Early in each session he showed the overt signs of hypoxia but continued his performance in a fairly uniform manner. However, without warning, he would collapse completely and require oxygen. After several seconds of oxygen consumption he would regain consciousness. Later he stated that he experienced no symptoms of approaching collapse.

Subject G. This subject did not suffer complete unconsciousness in any of the sessions. However, he was no longer able to continue the task, and judging from overt signs he was quite close to unconsciousness at the time he put on his oxygen mask. He reported after the 17,000-foot session that "the blocks suddenly began to move around on the board themselves, so I decided I'd better quit."

Subject H. This individual demonstrated the most consistent performance of all subjects. He continued working at a rather steady pace until just prior to collapse. There were no outstanding physical or psychological symptoms. He continued at the task until his head fell forward and his mask was put on by the examiner.

Subject I. This subject fluctuated in his moods throughout the more severe sessions. Generally he was rather complacent in the early portion of the experimental periods but gradually would become euphoric. However, he was able to control his behavior so as to avoid collapse. Generally he continued in this manner until he reached a point of complete stupor during which he would just stare at the blocks without making a move to solve the problem. His comments after collapse at 17,000 feet were, "It was taking a lot of concentration to pick out the right blocks. On several occz
felt very sullen."
lapses of conscious
that taking off and [illegible]
helped him to orient himself and to recover temporarily from his stupor. He also stated that he felt on the verge of collapse just as another subject lost consciousness in a rather violent manner and that this stimulus was sufficient to "bring him around" for a few minutes.

Subject J. This individual collapsed during the 17,000- and 18,000-foot sessions. The sequence of the behavior changes was the same in both sessions. He gradually became euphoric and reacted to incidents in the chamber as if he were mildly intoxicated. This pattern would continue until the subject started to laugh heartily and could no longer control himself. Attempts to get him calmed down so as to continue with the task were unsuccessful as the laughing continued and became more intense. At this stage it was necessary to give him oxygen. By the end of the 16,000-foot session this individual was very close to collapse but did manage to "hang on" until this session was completed.

Figure 16 of the Appendix is a reproduction of the comments made by one subject during the 17,000-foot session. The effect of impaired motor coordination is noticeable in the changed quality of hand writing. In addition, as hypoxia progressed one can detect the loss of inhibitions and a tendency to become rather childish.

From this discussion it is quite apparent that there were major inter- and intra-individual differences in the pattern of disorganization. All individuals did not actually suffer the same degree of impairment at the time of collapse, nor in all cases did a given individual reach the same degree of impairment during each of the high altitude sessions. The significance we obtain in analyzing the combined data occurs in spite of these factors. It might be assumed that if it had been possible to control the degree of impairment at collapse our findings would have been even more clearly defined.

Significance of the Blocking Effect

For our purposes, a block has been operationally defined in terms of the task performed under certain prescribed conditions. The assertion that some sort of block in response occurred as a function of hypoxic stress was inferred from the fact that periods of low efficiency were interspersed with periods of high efficiency. The present research does not permit us to describe the physiological background responsible for the presence of recurring periods of lowered efficiency. However, we may speculate on the relationship between block responses and the maintenance of efficient performance by the individual.

Since the level of performance tends to remain constant under continuing stress, we might infer that blocks are some sort of compensatory mechanism that permits a steady state between the block periods. This explanation is congruent with Bills' hypothesis that blocks are automatic rest periods. Considering the block as a form of compensatory mechanism is based upon an assumption of energy depletion at a rate proportionate to the stress. As the stress continues, an increase in rest periods or blocks is required to maintain stable performance.

A second explanation of the blocking effect might be that the block is a sign of disorganization rather than a compensatory mechanism. That is, the block is not a period of inactivity which allows the recuperation of tissue but rather is a period of heightened activity during which the organization of behavior is disrupted. This explanation would be congruent with what we know of emotional and speech blocks. For instance, speech blocking, under certain conditions, might increase in frequency and severity with increasing degrees of perceived stress. Since the blocks increase with degree of stress, one might maintain a constant rate and quality of speech between the blocks. However, it is evident from observation that the speech block is not a rest period but rather is a period of disorganization and heightened activity. A more appropriate explanation, and one which would also seem to fit our observations of such cases, is that the block is a sign of disorganization of behavior rather than a compensatory mechanism.

This conception would also seem to apply in the case of response blocks on a free association test. As we increase the frequency of critical stimulus words for an individual, the blocks are likely to become more frequent. In this situation we do not look upon the blocks, or increased response latency, as compensatory intervals but rather as periods of disorganization of behavior.

It seems appropriate to assume that the greater the degree and duration of stress, the greater the probability that neural disorganization will occur. These periods of disorganization are reflected in the behavior of the individual by temporary intervals of lowered efficiency. The fact that behavior improves after these block periods does not permit us to infer a cause and effect relationship; i.e., that the blocks act as rest periods to compensate for increased stress. Rather, an explanation more in keeping with the observation that these block periods are intervals of heightened activity is that blocks are merely overt signs of neural disorganization.

If the block interval is considered as a period of intense, disorganized activity, we must account for the fact that this is followed by stable behavior. The data of this research do not permit a solution to this problem. Therefore, if the second explanation of the blocking phenomena is accepted, the question as to the reestablishment of equilibrium must remain unresolved.

Correspondence of Physiological and Psychological Measures

The contention of this paper is that the relationship between decrement of performance and continuous hypoxic stress is saltatory. It is just such a relationship that one would expect from our knowledge of the physiological compensatory mechanisms.

Figure 12 is a schematic diagram of an anoxiaphotometer record. By way of explanation, the anoxiaphotometer is an apparatus which provides a continuous measure of the oxygen saturation of arterial blood.

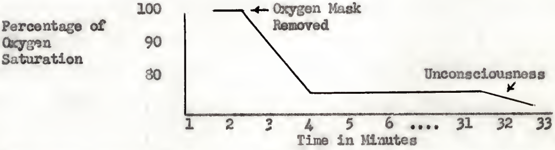


Fig.12. Schematic Diagram of Anoxiaphotometer Record

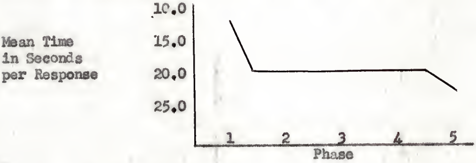
It is apparent from this diagram that the relationship between duration of stress and oxygen saturation is not continuous but stepwise. Immediately after the introduction of stress there is a period of instability. This is followed by uniform and relatively constant saturation which is maintained until just prior to collapse, at which time there occurs a rather sudden drop.

Figure 14 of the Appendix is an actual photograph of an anoxia-photometer record taken during exposure to 17,000 feet altitude. This record does not continue until the subject reached complete unconsciousness but is sufficient to demonstrate the saltatory relationship between continuous hypoxic stress and arterial oxygen saturation.

This relationship can be explained in terms of the principles of homeostasis. The physiological compensatory mechanisms allow the organism to attain a balance with environmental stress. This equilibrium is maintained until the limit of compensation is reached, at which point unconsciousness rather suddenly appears and the organism then continues to function on a visceral level.

Our analysis of the decrement in performance excluding blocks presents a similar picture to that found with physiological measures. We find an initial decrement, followed by a period of uniform performance which continues until collapse. There are numerous reasons to account for the fact that this similarity of physiological and psychological data is not more clearly defined in our evaluation. Probably the most important reason is the fact that the end point of performance was not the same for all subjects at the same altitude. Subjects were permitted to put on their oxygen masks if they felt they were on the verge of collapse. The end point then became dependent upon the individual's ability to judge how near to collapse he was. For this reason the final phase in some cases may have included only a few responses after the period of constant performance. In other cases, with subjects who continued to perform until complete collapse, the last phase of performance showed a rather sharp drop in performance efficiency. The division of performance into numerically equal units also is a factor which served to mask the similarity between the physiological record and the measures of performance. This may be seen in the hypothetical example given below.

Number of Responses 30 30 30 30 30 Total = 150



Although the number of responses is equal in each of the phases, the behavior change is quite sudden in the midst of the first and final phases. It was hoped to avoid this difficulty by drawing performance curves for each subject at a given altitude and matching them at the points of sudden change in performance. However, this was not possible with the present data. The nature of the individual's decline just prior to unconsciousness and the fact that all individuals did not continue to a comparable degree of impairment possibly account for this situation.

Our discussion concerning the patterns of disintegration among the various individuals clearly indicates some of the factors which would tend to obscure the similarity between the physiological record and psychological measures.

It has been indicated previously that in many cases there was very little difference in the subjects' performance at 17,000 and 18,000 feet. In fact, a few of the individuals, as has been noted, remained conscious longer during the 18,000- than during the 17,000-foot sessions. This may be accounted for in part by intra-individual differences in the compensatory mechanisms from one session to the next. Slight differences in general physical well-being at the time of the two sessions would bring about some differences in performance. Changes in attitude or motivation toward the experiment may also contribute to some extent. However, the probable major reason for the similarity of behavior during these two degrees of stress is the fact that we may be approaching the limit of the subjects' compensatory capacity. That is, when a certain critical degree of stress is reached, there is no longer adequate compensation and this will be reflected in small or chance differences in measures of performance.

Suggestions for Future Research

As stated in the first chapter of this paper there have been few research investigations concerned with the study of the decrement of the higher thought processes under continuous hypoxic stress. Consequently, there are many problems in this area worthy of scientific inquiry.

Specifically related to the present study is the problem as to a more definitive analysis of the behavior during the atypical response periods. The nature of the measuring instrument used in this investigation did not permit such an evaluation. The utilization of a task which would allow a determination of the amplitude of the individual block periods would seem to be a worthwhile research endeavor. Perhaps a complex discrimination task in which the responses consume only a very short temporal interval would be appropriate. With such a task, the block responses could be more easily detected and, unlike the present study, would not be imbedded in a complex series of responses covering an extended period of time.

Not only does the present investigation suggest further research utilizing different tasks but, in addition, arouses speculation as to the applicability of these results to other types of stress situations. It would seem a profitable research effort to determine whether or not the blocking effect and the saltatory decline of performance are also present under conditions of fatigue, alcoholic intoxication, extreme temperature ranges, and in those situations in which the individual is under the influence of various drugs and sedatives.

Should a similarity be demonstrated between the behavior pattern resulting from hypoxia and other types of physiological stress, the next logical question would be the correspondence between these behavior modifications and those resulting from psychological stress. The literature dealing with pathological behavior resulting from functional disorders is replete with examples which might be considered blocks in the stream of behavior. The alternating periods of disorientation and lucidity noted in many psychoses suggests a similarity with the behavior noted under severe hypoxic stress. Although this may be only a surface similarity, it does suggest the value of further inquiry into the correlation between the disorganization of behavior under both physiological and psychological stress.

A more general consideration of this research leads to the question of the relationship between the disorganization of behavior under hypoxic stress and the organization of behavior involved in learning a complex task. The present study demonstrated the blocking phenomena and the saltatory relationship present in the disorganization of a learned response under hypoxic stress. One might ask, is the organization of behavior required in learning a complex task characterized by the blocking effect? In the process of mastering a skill, is there an initial period of rapid acquisition followed by stable periods of no improvement? Within this framework, reminiscence might be accounted for by the absence of block responses following a nonpractice interval. The plateau phenomena, found in many learning situations, might correspond to the saltatory relationship demonstrated in the present study. It is recognized that these are merely conjectured relationships, but it does seem of value to consider as research possibilities the correspondence between the organization and the disorganization of behavior.

CHAPTER VI

SUMMARY AND CONCLUSIONS

This research was undertaken to evaluate several hypotheses regarding the decrement of performance under varying degrees and durations of hypoxia.

The results of the investigation allowed us to accept these hypotheses and to draw the following conclusions:

1. As measured by the task utilized in this investigation, there is a significant decrement in conceptual reasoning, and this decrement increases with degree of stress. A significant loss of efficiency was demonstrated at a simulated altitude of 13,000 feet, the lowest degree of stress to which the subjects were exposed. This loss was evidenced by an increase in mean time and variability of response.
2. It was shown that under hypoxic stress responses occur which consume a much longer temporal interval than those immediately preceding or following the delayed response. This behavior was considered to be indicative of the blocking effect. All responses exceeding plus 3.09 standard deviations from the subject's mean performance during the final practice series were designated block responses. It was established that blocks tend to increase in frequency with

degree and duration of stress.

3. If efficiency of performance is evaluated in terms of mean time and variability of response, we find an increase in both as a function of continuing stress. If, however, the block responses are omitted from the evaluation, we find a saltatory relation existing between efficiency of performance and continuing stress. That is, there is an initial decline after which a constant level of performance is maintained until collapse.

Throughout the previous discussion we have emphasized efficiency and uniformity of behavior when certain responses are abstracted from the data. From a strictly statistical point of view this uniformity may not be particularly unusual. However, from a behavioral point of view this finding seems to be of major import. As an example, Figure 13 shows the percentage of total time during which the group functioned at a level comparable to their performance at sea level.

It may be seen from this graph that the criterion for normal functioning was established at the mean plus 1.96 standard deviations. This limit is much less than the block criterion of plus 3.09 standard deviations. In addition, these limits were established on the basis of the individual's performance during the last 40 practice trials when he was comfortably seated at a desk and not in the decompression chamber. For this reason, and also the rigid criterion used in this case, we find a number of block responses during the sea level experimental session. However, it is quite apparent from the graph that even during the final phase of the most severe degree of stress the subject functions within normal limits approximately 30 per cent of the time. In other words, under severe hypoxic stress, even just prior to collapse, the individual has lucid periods during which his efficiency is approximately equal to that of which he is capable at sea level.

This investigation has indicated that efficiency of performance does not gradually decrease as a flashlight might burn out as the available energy is depleted. Instead, we have periods of apparent stoppage followed by constancy of performance and again failure of response. These periods of inactivity interspersed with lucid intervals become more frequent until final collapse, when continual response failure occurs without intervening periods of lucidity.

A compensatory function may be ascribed to the presence of response blocks or they may be considered merely as temporary lapses of behavior organization. The generality of this phenomena is open to experimentation using varied tasks and other types of stress situations. Such research may demonstrate that the behavior of the human organism under stress does not deteriorate in a continuous fashion but rather in a saltatory manner from higher to lower levels of organization.

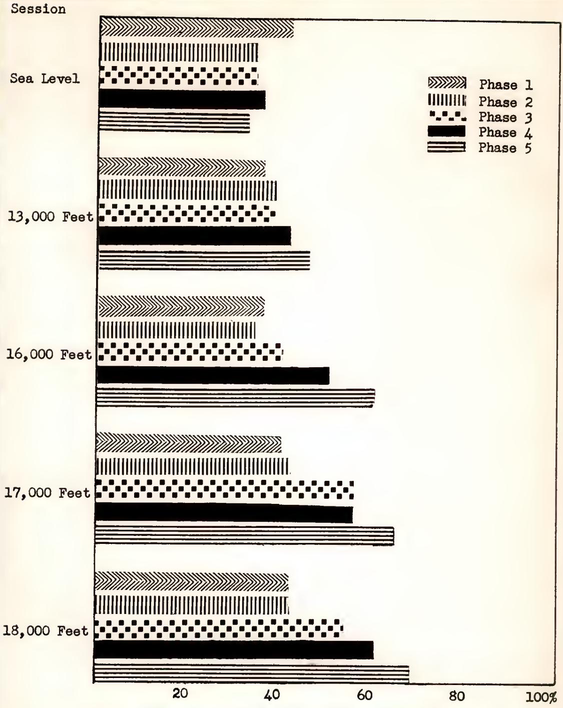


Fig. 13.—Percentage of Time Responses Exceed M + 1.96 SD

APPENDIX

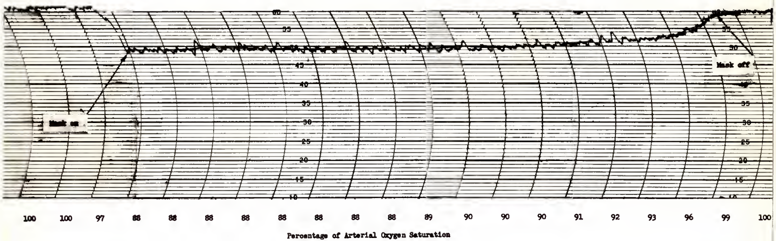


Fig. 13—Anoxiaphotometer recording at 17,000 feet. Due to the recording mechanism this figure must be read from right to left. Distance between curved lines represents one minute.

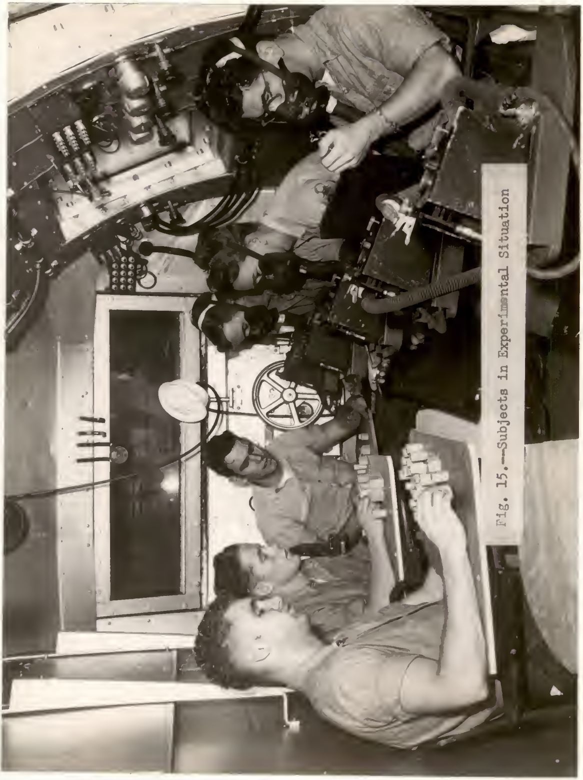
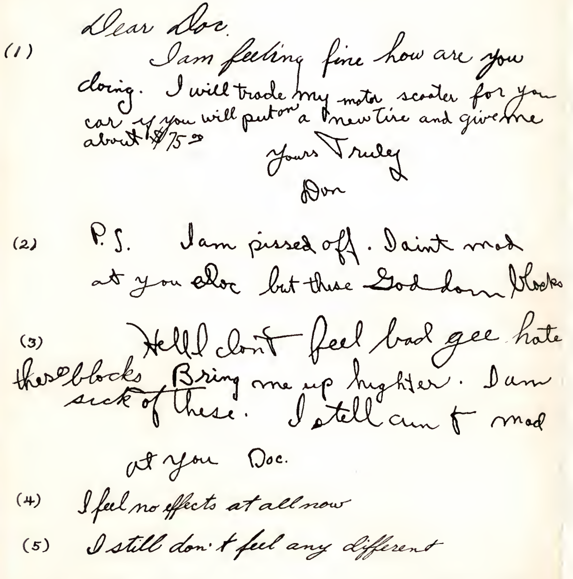


Fig. 15.—Subjects in Experimental Situation



Dear Doc.

(1) Iam feeling fine how are you doing. I will trade my motor scooter for you car if you will put on a new tire and give me about $75.00

Yours Truley

Don

(2) P. S. Iam pissed off. I aint mad at you Doc but these God dam blocks

(3) Hell I dont feel bad gee hate these blocks Bring me up highter. I am sick of these. I stell ant mad at you Doc.

(4) I feel no effects at all now

(5) I still don't feel any different

Fig. 16.--Comments made by subject during exposure to 17,000 feet simulated altitude. Loss of inhibition and impairment of motor coordination may be noted prior to the fourth comment at which point oxygen was administered.

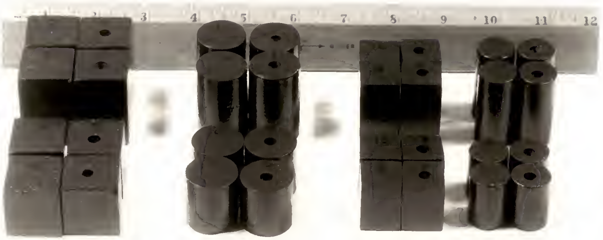


Fig. 17— Conceptual Reasoning Test

Subject ______________________ Session ______________________

Model	Time	Error
1. Large Square		
2. Round Letter		
3. Large Solid		
4. Large Number		
5. Tall Large		
6. Solid Letter		
7. Short Round		
8. Hollow Letter		
9. Short Small		
10. Number Solid		
11. Tall Hollow		
12. Short Solid		
13. Large Round		
14. Small Letter		
15. Tall Square		
16. Square Letter		
17. Small Round		
18. Number Small		
19. Large Hollow		
20. Number Short		

Fig. 18.--Recording Sheet for Conceptual Reasoning Test

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Clinton H. Maag was born November 22, 1920, in Cleveland, Ohio. He enrolled in Ohio State University during 1939 and remained there until he entered the Armed Service in 1942. The author served with the U. S. Army Air Force until November, 1946. After discharge from the service he returned to Ohio State University and obtained his Bachelor of Arts degree in 1947. The Master of Arts degree was conferred by the same university in June of 1948. After serving a psychological internship the author entered the University of Florida, where he pursued his graduate studies until August, 1951. At this time he accepted a position as Research Psychologist with the U. S. Naval School of Aviation Medicine, NAS, Pensacola, Florida, where he remains at present. The author is an Associate of both the Florida Psychological Association and the American Psychological Association.

This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of the committee. It was submitted to the Dean of the College of Arts and Sciences and to the Graduate Council and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

June 7, 1954

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